Fourth Edition

SOLAR THAT REALLY WORKS!

• cabins • caravans • campervans • motor homes

Collyn Rivers

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Contents

The problem is not so much what people don't know, but what they think they know that simply isn't true.
Ample Power Company

Preface

Solar That Really Works! was initially available (in 2002) as two editions: for caravans and motor homes respectively. Then, fifth-wheeler caravan ownership rocketed. As these have characteristics of both caravans *and* motor homes it made sense - in 2008 - to combine the editions - (and to include cabins).

By 2011, changing technology necessitated a revised and expanded third edition. Growing sales enabled a higher reproduction quality, four colour and more pages. This 2016 (now fourth) edition is fully updated. Despite all these changes, it remains at its original 2002 price.

Powering fridges, lights, TVs etc from solar energy is neither difficult nor complicated. Nor is planning the system. Anyone comfortable with basic tools will have little difficulty installing and connecting the various (12 volt) bits and pieces. Work on 230 volts legally requires a licensed electrician.

To make it work successfully we need to know how much solar energy is available where and when. We need to know what can realistically be run from solar energy. We particularly need to know what cannot. We also need to know what to specify, buy, and then do to make it all happen. Get this right and solar works superbly. Get it wrong and it doesn't.

Much of what we need to know has been thoroughly understood for decades. Battery technology was well understood by the 1890s. Text books of that era are still relevant. The essential electrical laws were formulated (by Georg Ohm) in 1826. Edmond Becqueral discovered the basics of what became photo-voltaics (solar energy) as early as 1839. The principle behind the fuel cell was discovered in 1843, by Sir William Grove.

Where feasible, this book uses everyday English. To avoid confusion, it uses technically correct (ISO) units and abbreviations and, for legal and other reasons, the legally prescribed term ('Extra-low voltage') for 12/24 volts where to do otherwise might confuse. 'Mains' voltage (a now nominally 230 volts) is known technically and legally (but sometimes confusingly) as 'Low-voltage'. In the USA, the power supply (known there as grid power) is nominally 120 volts but 240 volts three-phase power is also widely used.

This book is intended as a means to an end, rather than a text to be learnt. To avoid the need for memorising stuff that may never be needed again there is some deliberate repetition. For those with little or no electrical knowledge - please read 'Electricity Explained' on pages 95-96.

Where commercial products are named or mentioned it has been done (without charge) for the purposes of illustration. Endorsement is not intended nor should it be assumed.

The author discloses minor involvement (between 2006 and 2010) in the specifications and subsequent testing of the Redarc BMS 1215 unit, and also of long term testing of Webasto diesel heaters. Both were undertaken on a totally none-payment basis.

For those seeking to buy, design and build large solar systems for homes and properties the author also offers the companion volume *Solar Success*. Details are on successfulsolarbooks.com

For in-depth coverage of vehicle electrics, the companion book *Caravan & Motorhome Electrics* too is written in substantially plain English. This book too sells globally.

The author

Following three years in the RAF as a ground radar engineer and two years at de Havilland Propellers, Collyn Rivers joined General Motors (Research Laboratory). In the 1960s he drove a big 4WD twice across Africa, studying track surface conditions. Collyn then moved to Australia, spent five years designing everything from X-ray scanners to 500-tonne concrete presses, and three years as Applications Engineering Manager of Natronics Pty Ltd.

In 1970, he founded the worldwide magazine *Electronics Today International (ETI)*, which, in 1976 was awarded the title of 'Best Electronics Publication in the World' by the Union International de la Presse Radiotechnique et Electronique. With seven international editions it was also the world's largest.

Collyn subsequently founded and published over 20 other publications in electronics, computing, music, and telecommunications - including *Australian Communications*. From 1982-1990 he was technology editor of *The Bulletin* and also *Australian Business*.

In 1986, Collyn wrote the Federal Government's *Guide to Information Technology*, also the NSW Government's textbook for its electronics practique syllabus.

Collyn's current books are *Campervan & Motorhome Book*, *The Camper Trailer Book*, *Caravan & Motorhome Electrics*, and *Solar Success* (for home and properties). All sell globally.

Acknowledgement

The author acknowledges the assistance provided by many companies in allowing their illustrations etc to be used here, and also advice provided by Redarc in connection with battery charging.

I especially thank Laurie Hoffman for her invaluable advice in the mobile telecommunications area. In keeping with the spirit of this book, it was done whilst camping alongside the Murray River in her hi-tech motor home.

Solar realities

On clear days around noon, up to 1000 watts of solar energy (enough to boil a kettle in about five minutes) is theoretically available on each square metre of much of the Earth's surface. Commercially available solar modules can now (2016) convert only 20.5% or so of that energy into electricity.

By using appropriate and efficient appliances, however, such solar can free recreational vehicles and cabins substantially or totally from mains, alternator or generator power.

Whether the application is an RV, a cabin or a big property system, the fundamentals are similar. Differences are mostly a matter of scale. A good starting point is to know approximately the amount of energy different things require. Apparently similar lights and appliances may use hugely different amounts to achieve the same ends. Many older fridges use two to three times the energy of those made recently. Microwave ovens draw more current than many people think. Depending on how it is done, water pumping may require vast amounts of energy. Or very little.

Where can solar energy be used?

It is light, not heat, that solar modules turn into electricity. Most solar modules lose output when hot. They work best in cold places under a bright sun. The amount of energy they produce depends on how much light (not heat) falls on them, and for how long. All need at least *some* sunlight to operate. None work in total shade.

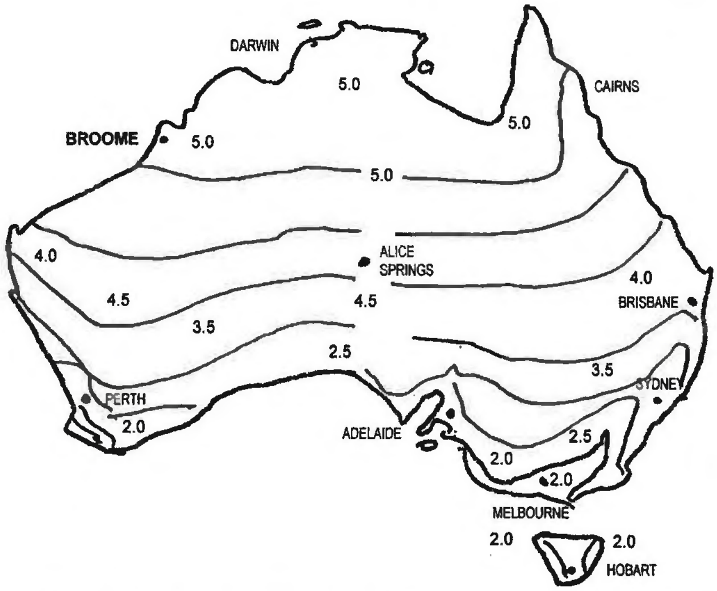
A solar module's output is measured in so-called 'Peak Sun Hours' (PSH). Each is like a standardised drum full of sunlight. That drum may 'fill' in only an hour or so in Cairns or Broome most year-round, but may take all day during Melbourne mid-winter. Each full drum can be seen as holding the equivalent of 1 PSH. The PSH concept (conceived by the solar industry) usefully averages the measurement of one's daily solar energy. (Think of sunlight as rain captured in a rain gauge and you've got the general idea.)

Our previously owned OKA in Kakadu National Park (1998). Two 80-watt Solarex modules provided ample power for all needs - including a 71-litre Autofridge. During our entire ownership, from mid-1996 until August 2006, the batteries did not once run out of power. The spade marks where the damper was cooking. Pic: caravanandmotorhomebooks.com.

The map below, shows the Peak Sun Hours for a typical Australian January (mid-summer). Irradiation varies more or less linearly from mid-summer to mid-winter. In many places and times, there will be at least 3 PSH each day. In some there will be 7 PSH or more. Full-size versions of these maps for Australian summer and winter are reproduced on page 47.

New Zealand's North Island, and the eastern part of the country's South Island have a fairly uniform 4.2-6.5 PSH between September and June, and 2-4 PSH in between.

Meteorological offices have solar irradiation maps for almost anywhere but these require you to juggle scientific units. Here, the numbers shown are Peak Sun Hours. Multiplying the solar modules' *true wattage* output each day by the PSH shown is the number of watt/hours you can, on average, expect each day.



Peak Sun Hours (mid-Jan). Multiplying the data shown by a solar module's true wattage gives the total average output for that day in watt-hours/day. This map, plus that for mid-July, is reproduced at larger scale on page 47.

'True' wattage output is emphasised because the solar industry's unusual way of rating module output causes the solar unwary to expect 25%-30% more than they thought they had paid for. This particularly catches out those who understand electrics and/or physics - but not the curious ways of the solar industry. (Page 17 explains how and why).

To ensure you will have a robust solar system that still works in less than optimum conditions this book advises to design an RV system assuming a absolute maximum of *only 70%* of the rated solar module output. If space permits, 50% is safer. (Solar capacity is now so cheap that cost is usually less of an issue.)

Peak Sun Hour maps allow for average seasonal cloud cover, but there are day to day variations. Input typically halves during heavy cloud, bush fire smoke may reduce it by two-thirds, but it is rare to have no solar input at all. Output is usually high on sunny days that have very light haze. It may increase yet further if sunlight is reflected from water or light sand, and back up to the haze layer, from where it is reflected down again.

Shortfalls resulting from long periods of cloud cover and night-time usage are covered by drawing on energy stored in battery banks. These typically provide three to five days reserve. Larger systems, and those with electric-only fridges, are likely to have generator or fuel cell back-up.

Solar limitations

Subject to the above, solar can be used successfully in most temperate areas. Differences in its scale and implementation primarily depend on the various needs, finance and (very much for most RVs) space and weight carrying ability.

The weight carrying capacity of a vehicle's axles, wheels and tyres is governed by legislation. As that capacity is directly related to cost, most RV builders provide what many owners believe to be less than adequate provision for payload. Included in that payload are gas, water, food, personal possessions: in essence everything placed in that vehicle after it leaves the factory. Even 'optional extras' specified in the original contract are typically installed by the dealer and likely to further reduce available allowance.

A few small specialist companies will, within reason, build whatever you seek. For most caravans the personal allowance rarely exceeds 250 kg, and 350 kg respectively for single and twin-axled units. Many campervan and small motor home makers provide the maximum possible living space in vehicles still light enough to be driven by holders of a car licence. This has resulted in a caravan-like situation: loading space may be available but weight restrictions limits its usage. This is less of an issue with larger motor homes. Their load carrying capacity is less limited and their length allows more space for solar modules.

If building your own RV, beware of believing weight does not matter. If you avoid MDF (a form of chipboard) you should be able to accommodate the weight of solar modules, generator and batteries.

Weight carry issues until recently restricted battery capacity but the much lighter lithium-ion batteries now ease this issue. Pages 22-28 refer. Assisting too is still-increasing solar module efficiency.

Fifth-wheeler caravans

Some fifth-wheelers' axles and running gear have limited payload capacity but it is usually feasible to house some part of the battery bank behind the cab of the towing vehicle or in under-floor lockers. Having some solar capacity on the towing vehicle's roof enables that vehicle to be in the sun and the trailer in the shade or partial shade.

Converter electrical systems

Almost all US made, and now many locally made, RVs have 12 volt systems of which the battery back-up is intended only for occasional single overnight use away from 230 volt power. These systems are close to useless for camping. (Pages 86-87 address this - and also compliance issues in general).

Cabins

Cabins have fewer restrictions. There is usually ample space for solar modules and batteries. Theft was initially an issue but less so as solar module cost dropped dramatically after 2010.

For cabins used irregularly, sealed lead acid deep cycle batteries can safely be left permanently on charge as long as the necessarily high quality solar regulator is programmed for the specific battery type.

Providing they are fully charged beforehand, AGM batteries may be left for 12 months or so before dropping below about a (non-damaging) 60% remaining charge at ambient temperatures below 25^0 C. Gel cell batteries are less accommodating but can be left for two/three months between fully recharging.

Both types need only a tiny float charge and few chargers can be programmed to do this. AGMs in particular are damaged in overcharged. Lithium-ion batteries are claimed to be able to be left for many months if 50% charged but if planning to so have that claim confirmed in writing.

This 11.3 metre fifth-wheeler built by Glenn Portch is exceptional in weighing only 3200 kg. It has a payload of an extraordinary 1300 kg! Pic: Glenn Portch.

Battery capacity

With battery capacity, 'more' only rarely means 'better'. Lead-acid batteries are damaged if routinely deeply discharged. Further, if the battery bank is overly-large relative to the charging source, that source may not be available to recharge it fully, let alone quickly.

Adding more batteries *alone* is like opening more bank accounts for the same deposited money. All that can do is to increase the overhead losses. Economise on batteries but never on solar modules. As a very rough guide you really need 200 watts of solar for every 100 amp-hours of a 12 volt battery. Ideally have more as that improves charging in overcast conditions.

If you use energy-hungry arc welders and/or big angle grinders etc only occasionally, scale the system for 'normal' loads. Supply the rarely used excess by a generator. This also applies if planning to spend only an odd winter month in places with short hours of sunlight (despite lower fridge energy usage in winter).

Cooking & heating

As roof space for solar modules is limited, solar generated electricity (alone) is not practicable in RVs shorter than about 7 metres for anything that, *as its main purpose*, generates heat. Electric ovens, fryers, and water heaters are out. Hair dryers are borderline. Electric irons are best used where there is mains power. For such RVs, use gas for cooking and for heating water. For cabins, use gas for cooking, and solar water heaters for water heating generally. (Some RV owners also use portable solar panels but they are cumbersome and only too readily stolen.)

Energy-efficient appliances

Coffee grinders, blenders, and other small appliances vary in efficiency but, if used normally, their energy use is rarely of concern. Microwave ovens, however, use more energy than many suspect. Their wattage rating refers to the work they do (i.e. 'cooking power') *not* the energy used in such cooking.

Most '800 watt' ovens consume close to 1350 watts, or 1500 watts via an inverter. Ten minutes use may draw a day's output from a 100 watt module. That oven may thus cost only $195 or so, but running it from solar can add many times that for the extra solar capacity and battery capacity needed to drive it. And it can *still* only be used when there's enough power. Excepting for big rigs with ample solar capacity, or a generator, consider running a microwave only when you have 230 volt mains access.

Water pumping

Apart from hand or foot operated pumps (both are still available) the only practicable pumps for RVs are those that run from 12 or 24 volts. Mains-voltage pumps are available but they use several times as much energy for pumping the same amount of water.

Where there is a washing machine or dishwasher, and also in large cabins with flush toilets, a 'pressure accumulator' (page 40) overcomes the otherwise high energy draw of pumping water. It also results in a system that does not fluctuate in pressure, is silent most of the time, and saves electrical energy. There are also variable speed pumps that provide constant pressure.

Washing machines/dishwashers

Most front loading washing machines use less energy and water than top-loaders. The more efficient units run readily from a medium-sized RV solar system and inverter. They wash well using only cold water as long as cold water washing powder is used. These machines are fine also for cabins. Many current models draw only 200 watts or so when run from cold water.

Dishwashers need a hot water supply. It is not feasible to supply this via solar electricity, but a number of owners have built their own thermal solar water heaters from coiled copper tubing or black poly pipe. If doing so, to avoid scalding (especially for children) it is essential to include a 'tempering valve' (from plumbing suppliers) to ensure the water does not exceed 50^0 C. In some states it is legally required.

Television

Unless left on day-long, there are no major energy problems with post-2014 TVs with 36 inch (92 cm) LED screens. Most now draw about 60 watts. Older ones may draw over 150 watts. Almost all 12 volt TVs are made primarily for use in underdeveloped countries and use old energy gobbling technology.

Computers

The most realistic choice for RVs and cabins is a laptop. As with TVs, conventional screens are responsible for about half of the draw - and by much the same amount. LED screens draw less. See also page 41.

Allow for the energy draw of charging iPads etc, also that drawn by communication modems. Specialised games-playing computers use *far* more energy - and are used for longer times.

This Sony Bravia 32 inch TV draws 55 watts. Pic: Sony.

Lighting

Incandescent (230 volt) globes are no longer legally sold. Halogen globes use about half the energy for the same amount of light but were an interim technology now mostly replaced by light emitting diodes (LEDs). Fluorescent globes and tubes, and compact fluorescents, use only a quarter of the energy of incandescent globes. The very latest white and warm white LEDs use even less. Pages 36-38 refer.

Air conditioning

Given at least 750 watts of solar modules for this alone, solar-powered air conditioning is feasible for daytime use, but unless run from mains electricity, or from a generator, having air conditioning all night is not practicable in any but the very largest RVs.

Solar modules, air conditioners, and batteries are, however, becoming increasingly efficient. Later editions of this book may have a different view of the feasibility.

Evaporative coolers use much the same energy as big cooling fans but lose effectiveness above 25% humidity. Their vendors often claim they work in up to 40% humidity. But vendors sell them - they do not necessarily *use* them.

What voltage?

Twelve and twenty-four volt systems are cheap and simple. Their wiring is relatively easy (and legal) to install. There is negligible risk from electric shock.

One drawback (for 12 volts) is that surprisingly heavy cable has to be used to reduce energy losses (pages 59-65). There is a wide range of 12 volt appliances, but (apart from fridges), very few for 24 volts.

Some coaches and a few motor homes have 24 volt alternators and batteries. To run 12 volt lights and appliances, companies such as Redarc and GSL offer 24-12 volt charge equalising units.

Pic: original source unknown.

These draw the required 12 volts from one of the two series-connected 12 volt batteries used in most 24 volt systems, whilst constantly equalising the voltage across both. A more efficient approach for lighter loads is to use a 24-12 volt dc-dc converter.

Mains voltage via an inverter

An inverter provides mains-like electricity. Many seemingly identical units cost far less but may only be able to supply their rated maximum output for a second or two. (They only *seem* identical.) This is less of an issue with those over 1000 watts or so because they are made for a more electrically sophisticated market. More on inverters - pages 30-32.

Costs

The draw of a large electric fridge still dictates system size and cost. To safeguard against spoilage, it is advisable to have a back-up generator.

A microwave oven may cost only $195 but the solar capacity and battery capacity to drive it may add $1000. By all means have one, but (for small solar systems) run it only from a generator, or when you have access to mains power.

Solar is becoming cheaper, but battery capacity is not. Having adequate solar capacity alters the role of the battery. Sufficient battery capacity is still needed overnight and for dull days but, given sufficient solar, battery capacity can be reduced because solar modules charge to some extent even on overcast days.

Solar module price plummeted after 2010. Battery prices soared, but differ from vendor to vendor. It pays to compare prices but because most batteries are so heavy transport costs can wipe out bargain prices.

The seemingly promising small scale fuel cell technology seems stalled. That most promising, Truma's VeGA LP gas fuelled product, proved too costly. It was withdrawn from sale in 2014. The EFOY methanol fuelled product (page 29) is still on sale - but it's price has escalated since 2012.

Avoid cheap products

In the RV area particularly, unless you *really* know what you are doing, it is better to spend more and buy high quality products from well-established companies rather than seeking bargain-priced products of unknown provenance and often negligible technical support. There *is* the odd bargain on eBay but much is close to junk.

Electrically self-sufficient

To extend camping time away from mains power, many RV owners add an auxiliary battery that is charged from the alternator whilst driving. It is a long-range fuel tank approach that works for single overnight stays, particularly for a fast 'around-Australia' where most days entail sufficient hours of driving to fully charge that battery. But for more typical usage, and much of the time, that battery is likely to be only partially charged and overly discharged. Both substantially shorten battery life.

A better general approach is where all energy (and energy loss) on site is *replaced* on site such that batteries primarily cater for overnight use, and supplement energy on dull days. They stay closer to fully charged. You can thus stay on site as long as you like (electrically at least). It costs more initially, but batteries last much longer. Savings on battery replacements partially compensate.

Doing this is feasible providing energy requirements are realistic, and you are travelling where and when there is sufficient sun. This is most of Australia in summer and a fair part in winter. It makes no sense however to scale a system for an occasional mid-winter month in Tasmania, nor for occasionally running welders, big angle grinders, electrical clothes dryers etc. These are better run from generators.

Vehicle alternator charging

Relying on all or part charging from the vehicle's alternator entails driving fair distances most days. It is done by parallel connecting the starter and auxiliary battery so that both charge from the alternator. In most (pre 2013) vehicles this necessitates a voltage sensing relay. This relay delays charging the auxiliary battery until the starter battery is adequately charged (typically inside a couple of minutes).

Most alternators will charge a 10 amp-hour battery in 2-3 hours but only to 70%-75% of full charge. AGM, gel cell and lithium-ion (LiFePO4) batteries however charge more fully and faster. Pages 22-27 cover the increasingly preferred dc-dc alternator charging - plus complications in post-2013 vehicles.

Two 80-watt modules and AGM battery drove a 60 litre fridge in our previously owned Nissan Patrol. At the time this picture was taken (in 2008), the system also included a Redarc BMS 1215 battery management system, that we had on test for over two years. The Tvan had its own 50 watt system for water pump, lights, NextG and laptop computer, and a Webasto diesel water heater. Pic: En route to Mitchell Falls. Pic: copyright caravanandmotorhomebooks.com.

The self-sufficient approach

Given adequate solar capacity, alternator charging is not essential. The author's rig shown on the previous page had (manually switched) provision for alternator charging, but such charging was never needed during our six years of extensive use and ownership. Both tow vehicle and trailer had its own separate system.

Omitting alternator charging excepting for the starter battery simplifies wiring and installation. There is also less to go wrong. Because the solar regulator can be set up specifically for the batteries used, this more readily enables a conventional lead-acid battery to be used for starting, and auxiliary gel cell, AGM and lithium-ion batteries to be optimally charged for RV use.

Unless there is ample space for the solar modules required, this approach precludes fridges above 120 or so litres, and also microwave ovens unless used for only two or three minutes a day. The conventional solar plus alternator, generator (or fuel cell) approach covered later is thus recommended for such use.

This (Wagan) jump starter will supply peak currents of up to 700 amps - more than enough to start the largest 4WD. Pic: Wagan.

Jump starting

Starting assistance can still be obtained from the auxiliary battery via jumper leads.

A better method nowadays is to use one of the lithium-ion (typically) 18 amp-hour emergency engine starting units. Despite their small size and weight these units will readily start a big 4WD engine several times before needing recharging.

Future for alternator charging

There is an ongoing trend to reduce the output of vehicle alternators to that required by the needs of the base vehicle, plus minor allowance for (say) an upgraded sound system. It seems improbable that alternator output will be continue to be available for general RV use - as it can right now.

There are currently products on the market that overcome the voltage limitations of a temperature-controlled alternator (pages 23-27) by *directly* increasing the voltage output of the alternator. Leaving aside the ethics of seeking to negate emissions reduction, and that this interferes with the vehicle's computer systems, it is also illegal.

(The dc-dc and bcdc units described later in this book do not cause the alternator to generate higher voltage as such. They accept whatever it and, via electronics, raise its voltage.)

The long term source of 12 volt RV energy (apart from solar) is likely to be a new generation of small high-efficiency and very quiet small generators - such as the new Dometic TEC 29 2.6 kW low emissions petrol unit (shown right).

These can rapidly charge battery banks - but still best done during the day as even the quietest generator may bother campers at night.

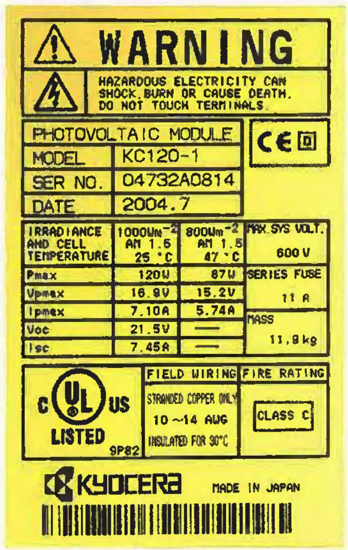
Released in mid-2015 this ultra-quiet TEC 29 petrol-engined generator from Dometic generates 2.6 kW. Pic: Dometic.

Solar modules

The solar modules most commonly used employ mono-crystalline or poly-crystalline technology and, unless otherwise stated, are those referred to throughout this book. Present day solar modules produce about 70% of their apparently rated output unless used in conjunction with a so-called MPPT (Multiple Power Point Tracking) regulator (pages 20-21). This anomaly is because the industry's SOC ('Standard Operating Conditions'), that are used also for promotion, are very far from *typical* operating conditions.

Solar modules lose about 5% of their output for every 10° C that they exceed a base-line of approximately 5° C. Vendors correctly claim that losses start at 25° C, but this misleads. That 25° C they refer to is that of the little black cells under a hot sun. Those cells are typically 20° C warmer. To achieve an even more ambitious output, the tests are done using a 'photo flash' to avoid heating.

The industry does not conceal this. It's official NOCT (Nominal Operating Cell Temperature) method states that, at 25° C *ambient*, the actual cell temperature is typically +47° C. This can be seen in the third column of the actual data panel shown on the right.



This data panel from one of own solar system's modules marketed as 120 watts as producing 87 watts under the NOCT rating. Pic: Author Broome 2008.

The alternative amorphous technology modules are less degraded by heat, but this is only of real benefit at the top end of Australia. They are also about twice the area of others of the same output. Fine for homes and properties - less for RVs.

What solar modules really produce

There are further reasons why solar modules do not produce that seemingly claimed. People who understand electrics or physics are particularly likely to be misled - in an unexpected way. They *know* that watts equal volts times amps so realistically assume that solar industry wattage (for a 12 volt solar module) is calculated at about 12 volts. But that's *not* how the industry does it.

To measure solar module output, voltage and current is monitored *separately*. The claimed output is whatever combination (of volts and amps) results in the highest number of watts. That's usually around 17 or so volts.

The industry justification is that *if* the nominally 12 volt load can withstand higher voltage without harm, and can thus do more work (as with some water pumps), that typically 16.8-17.2 or so volts *will* enable the load to get close to the claimed wattage output - if you are also on top of an equatorial mountain around noon on a cold but sunny day.

If, like most domestic buyers, you have a less improbable environment, and a system that runs at 12.0-12.6 volts, you are likely to get only a bit over 70% of what you'd probably thought you'd paid for. Vendors reveal this but in terms mostly only electricians understand.

The data panel (above) relates to a '120 watt' module yet clearly shows the probable Nominal Operating Cell Temperature (NOCT) output as being about 87 watts.

Multiple Power Point Tracking (pages 20-21) recovers part of this loss. The technology is built into most plus $200 regulators.

Shadow resistance

This term confuses many new to solar. No solar module works at all unless there is at least *some* light. Shadow resistance thus relates to how much output is lost when *part* of the module is fully shaded. Most lose almost all output if a third or more of the area has no sun. If half of such a module is shaded, there is next to no output. See also page 18 regarding amorphous technology.

Module placement

Roof-mounted modules for RVs are best installed close to horizontally (ideally having a slight slope for water run off). For cabins, they should face due north (in the southern hemisphere) and due south (in the northern hemisphere), and usually tilted at the latitude angle. It is possible to angle them for year-round optimum input, or (as say for a summer or winter holiday cottage) for seasonal optimum input. Complex tracking mechanisms are now rarely used except in high latitudes such as Tasmania. This is because solar module prices fell so dramatically after 2010 that it became far simpler and much cheaper to add more capacity to compensate for the minor loss.

Buying solar modules

Mono-crystalline modules have a uniform appearance. They usually cost more than poly-crystalline but are typically 3%-4% more efficient (a few now commercially available exceed 20.5% efficiency).

Poly-crystalline modules, also known as multi-crystalline modules, are cheaper but typically only 13.5% -14.5% efficient. As a generalisation, multi-crystalline modules (being smaller per watt) are preferable for RV use. Poly-crystalline versions are better suited for cabin and residential use where mounting space is usually less of an issue.

The now little-used amorphous modules have better heat and shadow tolerance, but whilst solar module development is generally resulting in more watts per unit area, amorphous module technology remains substantially unchanged. Only a few makers remain.

For mobile applications mono-crystalline modules now provide well over twice the output for the same size and weight - a compelling argument for their use, particularly where roof space is limited.

Amorphous modules may still be worth considering if space is not limited - and particularly where the ambient temperature is above 30^0 C for a substantial part of the year.

There are also 'double-sided' modules where the sunlight passes through an upper active layer, and is reflected back from a suitably shiny under layer, to a second active layer on the underside of the module. These (Russian) modules surfaced around 2008 but there has been little independent evaluation since.

Current solar module technology captures only part of the full solar spectrum. This limits the maximum achievable efficiency to about 35% (close to this has been achieved in specialised applications,

We experimented with tilting solar modules whilst crossing inland Australia in our rebuilt 1974 Kombi, but the gain did not warrant the effort. Pic: near Innamincka (1997), author's wife, Maarit in foreground. Who owns this lovely Kombi now?

corresponding to about 350 watts per square metre). To exceed this, a totally different technology is required. There *are* signs that this may happen. Scientists in the USA are working on a new approach that may well enable the full spectrum to be exploited: i.e. from near infra-red to far ultra-violet. It is unlikely, however, to expect general commercial use inside a decade or so.

Portable solar modules

A number of solar module and other vendors offer (usually pairs) of solar modules that when unfolded, are free-standing and can be erected to face into the sun at some distance from the RV.

Many portable units sell at a low price, but because copper is costly, have cable sizes that are *far* too small. As a direct result much of the energy is lost along that cable. It is usually possible to replace the original by the more suitable 6 mm^2 flexible twin core cable.

There are two main unit types. One (and preferred) is a basic module or two connected across the RV's existing solar regulator input - *not* the battery. The second type has a basic solar regulator inbuilt enabling the unit to be connected directly across the RV's battery.

These fold-up modules were made by Brian Fox. Pic: by Brian Fox.

Portable solar modules can be readily assembled yourself using a pair of hinges and an adjustable strut for tilting them to face sun angle.

Buying solar generally

When buying, decide what wattage and physical size/s best suit your needs. Then seek the lowest price for *known brands*. Don't get talked into 'after-sales service'. Solar modules need none.

High quality roll-up solar modules are also available. Pic: www.rolasolar.com.au

Almost all solar modules sold for RVs are of 36 cell. They generate maximum power at 16.8-17.2 volts, then reduced to the required safe charging voltage by the solar regulator.

A few (usually very small) solar modules are made with only 33 cells. They produce about 15.4-15.7 volts. These are intended for directly driving small fans etc. These are often described as 'self-regulating' but in the manner that starving people may be said to be on 'self-regulating' diets. They may however cook a small battery if left permanently connected in very sunny places.

Grid-connect solar modules

Solar modules made for grid-connect systems are often offered at *very* low prices. Most, however, develop voltages from 25-65 volts. They not compatible with basic stand-alone systems that have nominally 12 volt solar regulators that typically accept up to 21 volts or so.

These grid-connect modules are, however, often of high quality. Most can be used in conjunction with the MPPT solar regulators described on the following pages. These MPPT regulators accept a wide range of input voltages, yet can charge 12 volt and 24 volt batteries. Minor expertise is needed to know if this is possible as the input voltage range of such regulators varies. Not all can be so used.

Solar regulators & monitors

Solar regulators control the output from solar modules. They ensure batteries charge quickly and deeply, but do not overcharge. They may be left on permanently, as long as those batteries that still need it have their water topped up from time to time. Or replaced by sealed batteries.

Exceptions are AGM batteries not in regular use. Many manufacturers prefer these products to be initially fully charged, and then fully recharged only once or twice a year (i.e. not float charged).

A solar regulator is essential except where very small 33 cell modules (usually under 5 watt) charge conventional lead acid batteries of at least 100 Ah. Some people still do this without a regulator, but this risks damaging batteries and connected equipment through excess voltage. Those claiming to get away with it mostly use a module that is too small to overcharge the battery, or have such grossly inadequate wiring that voltage drop 'safeguards' the system.

The simplest form of regulator is a basic switch that connects the module/s to the battery until it reaches full charge. The switch then opens. It closes again when voltage drops. The more sophisticated regulators control charging current, as well as charging voltage. Some turn on and off constantly at very high speed, automatically adjusting the ratio of on-time to off-time in each on/off cycle.

Most regulators are programmable for conventional batteries. This typically needs re-doing for each different battery type, and voltage, capacity and time of day.

Basic Morningstar solar regulator is small but effective. Pic: Morningstar.

MPPT regulators

Some part of the voltage mismatch loss (discussed on page 17) can be partially regained by using a Multiple Power Point Tracking (MPPT) regulator. These devices juggle volts and amps to optimise watts. In effect MPPTs are dc-dc converters and work much like a torque converter in a car.

OutBack Power Systems solar regulator handles up to 70 amps. Pic: Author.

If a module is producing 17 volts at 5 amps, its theoretical and claimed output is 85 watts. But, as batteries charge at (say) 14 volts, the usable wattage is 14 volts times 5 amps (70 watts). The MPPT function converts that 85 watts into about 14 volts at 5.5-5.6 amps - about 77-78 watts. The seemingly claimed 85 watts is still not there but 77-78 watts is closer.

It is often claimed that the MPPT technique recovers 20%-30%. This is true but that mostly occurs only for a short time early in the morning, and evening and/or when batteries are deeply discharged. A daily 10%-17.5% is more typical. MMPT *does* work - but not as well as some vendors claim.

Some MPPT regulators accept solar input from 12-120 volts dc or more. Most are programmable to charge 12-48 volt batteries. This enables solar modules to be series-connected (page 76), in turn enabling lighter interconnecting cable to be used. This can be a major saving with big solar arrays. They are also useful where a little more solar energy is needed but there is no space available for extra modules.

Buying a solar regulator

Basic systems supplying a light or two need only a basic $65-$70 regulator. But for anything more ambitious, especially if that's an electric fridge, a top quality regulator is essential. It makes no sense to pay a lot of money on solar and battery capacity and then throttle it to save a hundred dollars.

Consider paying $200 upwards for a sophisticated solar regulator that includes monitoring functions. Stand-alone monitors (as shown below) work well, and are simple to interpret, but some cost as much as good solar regulators that include monitoring functions anyway.

Most such solar regulators now include MPPT technology. It is now common also in mid-priced units. Be *very* wary of claims of MPPT function for cheap eBay specials. Many are fakes (they are not MPPT).

Programming a solar regulator is usually not difficult once the manual has been read a few times. Teenagers are usually very good at this, but only rarely at explaining how.

Energy monitors - knowing the state of charge

Although solar regulators automatically control battery charging, one still needs to know how much solar energy is available, how much is being used, and how much energy remains in the battery. These functions are included within most solar regulators costing more than $200 or so, but can also be done well and more clearly (although usually more expensively) via stand-alone energy monitors.

What absolutely does not work is to attempt to tell deep cycle battery charge by measuring voltage.

A conventional lead acid's battery's charge is the result of chemical interactions between lead plates and an electrolyte. This interaction take many hours before charge is even throughout the electrolyte. It is also temperature related (the colder the slower). Any voltage reading during a charge or deep discharge, and for a long time after, reflects *only* the local electro-chemical effect on the plates' surfaces.

A well-charged battery that has just run a microwave oven may thus show 11.2 volts. This is often mistaken as being almost totally discharged. Conversely, a near-useless battery may show 13-14 volts within minutes of being put on charge.

Instant voltage readings often result in totally wrong assumptions. As a virtually direct result, perfectly good batteries may be thrown away and those worn out retained. Meanwhile owners search pointlessly for 'faults' that may not exist.

Readings of specific gravity were more meaningful, but impossible with today's sealed batteries.

How energy monitoring works

The *only* truly practical way of knowing the remaining charge works much as we track money.

Count what comes in, count what goes out, deduct one from the other (and the bank's ransom for their use of it meanwhile). The balance is what we have left.

Energy monitoring may be added to existing systems but most of the functions offered are standard inclusions on good quality solar regulators.

The unit shown is an example of a good and popular stand-alone energy monitor. It is marketed under various names including Xantrex, Victron and Enerdrive.

The functions typically include:

* Battery voltage.

* Lowest and highest battery voltage since midnight.

* Current flowing in and out of the battery

* Consumed amp-hours.

* State of charge.

* Time to go (how long batteries can support an existing load).

* Historical data.

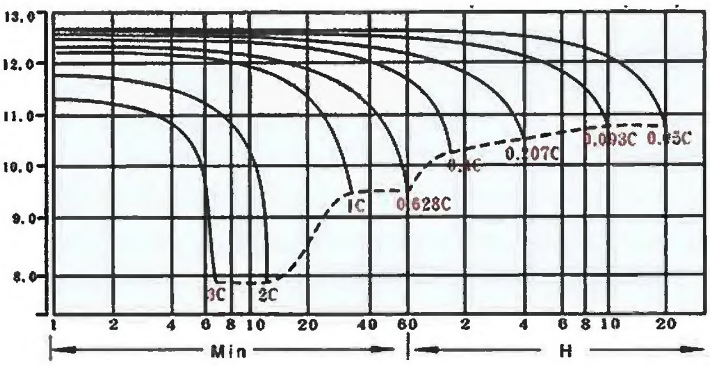
The need for battery monitoring may not be immediately obvious but it will quickly become so. Further, because most units record historical data, such monitoring eases fault finding.

Xantrex Energy Monitor is simple and very effective. Pic: Xantrex.

Batteries & battery charging

As noted previously, traditional lead-acid batteries store energy as chemical reactions between lead plates and an acid solution. They are made in various types and sizes and applications.

Starter batteries produce serious grunt for brief seconds. They are good at this, but will not withstand deep discharges.



The effective capacity of batteries is related to the load across it. The voltage drops to a level not usable by that load. If the load is reduced its full stored energy is still available. Pic: Long Chang Battery Co.

The *effective* capacity of a battery relates to the size of the load. The graph shows the 'effective' capacity of a 100 Ah battery at various loads. This capacity drops rapidly as load current increases.

This is commonly misunderstood as implying that the *remaining* capacity is reduced. It *is* still there - but only accessible at a lower rate of discharge.

A deep-cycle lead acid battery's life-span is primarily the number of amp-hours in and out. This can be a small number of deep discharges, a high number of shallow discharges, or somewhere in between, but the relationship is not linear.

Lead acid battery makers suggest discharging to 50% gives optimum life span and may enable 500-600 cycles of such use. Two thousand or more such cycles is not uncommon if you follow the self-sufficiency recommendations in this book, (where batteries rarely drop below 75%-80%). Correctly sized and maintained top grade deep-cycle batteries outlast all other types, but unless they are, so-called 'traction batteries' are a cheaper substitute. Ultimately how you use batteries is a monetary issue. It's almost as if you are buying 'n' amp-hours.

Specialised batteries

Gel cell and AGM (Absorbed Glass Mat) batteries charge faster. Ongoing deep discharging shortens their lives, but less so than doing that with conventional lead acid deep cycle batteries. They are larger, heavier and more costly - but partially offset by greater usable capacity.

AGM batteries need next to no maintenance. If first fully charged, they may be stored for a year or more if mostly below 25⁰ C, six months or so between 30⁰-35⁰ C.

Lithium-ion (LiFePO4) batteries

These use a *totally* different technology. They are about a third the weight and volume of other batteries. They charge much faster and can be discharged to greater depth without overly shortening their life.

Nominally 12 volt LiFePO4 batteries in typical RV use maintain 13.1-12.9 volts across most of their usable range of about 90% to less than 20% charge. They require a specialised and critical way of charging.

Individual (nominally 3.4 volt) LiFePO4 cells must be equally balanced and charge voltage not allowed to exceed a critical level.

Until recently most RV users bought individual cells that they connected to provide a nominal

Typical LiFePO4 batteries. Pic: Revolution Power.

12.8 volts, and added their own monitoring and control systems. Those required for *general* RV acceptance are direct drop-in replacements for existing batteries. These have only recently become available, but as of August 2016, are stocked by only a few specialist companies. Caution is required regarding claims about these batteries on Internet forums. Some, implying more output than input, are absurd. They defy basic physics.

Heavy loads - caution

Via an inverter, a typical 800 watt microwave oven draws 130 amps at 12 volts. Lead acid deep-cycle batteries can safely supply current at a rate of 5% of their Ah capacity. Gel cell or AGM batteries better withstand repeated heavy current draw, but 200 Ah or more is preferable. Any LiFePO4 battery likely to be used in an RV, however, will handle such current with ease.

Battery charging

A battery is charged by applying a voltage across it that is higher than the voltage it already has across it. The greater the voltage difference, the greater the charging current, and the faster the battery charges.

Earlier vehicle charging systems, and cheap battery chargers, generated an approximately (constant) 14.2-14.4 volts but, as the charging battery's voltage rose, that voltage *difference* accordingly decreased. Charging thus tapered off until, well before the battery was fully charged, charging effectively ceased.

Charging a battery from constant voltage is *always* a compromise. If high enough to charge a battery in a realistic time, but not cut off once fully charged, that voltage is likely to kill it. Most charger makers ensure the voltage is not high enough for that to happen inside many hours but, as a direct result, batteries so-charged do so slowly. They reach 70% in reasonable time but may take a day or two to fully charge, yet if left on charge for a week or more are still likely to be damaged or destroyed.

Charging is rarely a problem for engine starting: the system is designed accordingly. Further, the actual energy draw (of about 2% of the starter battery's capacity) is negligible. That charging regime is, however, a problem for big deep-cycle batteries. These too are limited by that tapering-off effect.

AGM and gel cell batteries accept higher rates of charge. They charge fairly well from constant voltage, and better and faster via the regime outlined below, providing the charging source has enough capacity. This regime, with minor variants, is built into virtually all high quality chargers.

(LiFePO4 battery charging is further discussed later in this Chapter.)

Dc-dc charging

Until 2000 or so, most alternators produced a constant 14.4-14.7 volts. This was sufficient to charge an RV's auxiliary battery in reasonable time, but remotely located batteries powering a caravan fridge via too thin cable suffered from voltage drop.

Some owners fitted voltage boosters close to such batteries to increase whatever voltage came out of the cable.

Early BMS 1215 under extended off-road testing. Pic: Author 2010.

By remedying voltage drop, this enabled fridges etc in caravans to work more effectively and waste less energy. The associated battery however still had fixed voltage charging - with its inherent limitations.

To ensure adequate RV auxiliary battery charging, units were developed that electrically isolate the whole auxiliary system from the alternator and boost voltage to whatever required for the RV battery.

These units, known generically as dc-dc chargers, are perceived by the alternator as just another load (e.g. spot lights etc). This have become by far the best way of alternator charging batteries of all (then) types of batteries, and particularly for the older lead acid deep-cycle versions.

Dc-dc chargers have a further and major advantage. Batteries located at a distance from the alternator, as with caravans, inevitably suffer from voltage drop along the feed cable. Whilst the previous voltage boosters helped, a dc-dc charger installed close to the caravan battery not only compensates for voltage drop: it optimises the charging regime for the size and type of battery installed.

To operate efficiently, the cable from alternator to dc-dc charger still needs minimal voltage drop. The dc-dc charger makers emphasise this, but not all installers use the specified cable sizes.

Dc-dc alternator chargers are fine for all fixed voltage alternators and for temperature compensating alternators (described on the next page) that *never* drop below 12.7 volts whilst driving.

The even more sophisticated version of these units, known as battery management systems, include solar voltage regulator input and (remote) energy monitoring. All accept whatever alternator and solar voltage is available and increase or decrease it, using sequences generally similar to that described on page 25. Some include a multi-stage 230 volt charger.

New alternator voltage problems

From 2000 or so on, many new vehicles had temperature compensating alternators. They charged at about 14.1 volts when the engine was cold, reducing to about 13.2 volts when the engine reached operating temperature. These alternators limited direct RV battery charging to 60%-70%.

This limitation can usually be overcome by using the dc-dc alternator charging or the battery management systems described above - but it is advisable to first check with their manufacturer.

From 2010, the ongoing moves to reduce exhaust emission pollution from motor vehicles, that includes minimising fuel usage, extended to minimising alternator charging. In late 2011 this extended to having the engine control unit (ECU) vary alternator voltage (and even shutting it down) as engine load changes.

These alternators are fitted to many new vehicles sold in Australia from 2013 onward and are likely to become virtually standard. An even tighter regime (Euro 6 Emissions) will be in force by 2018.

The output from ECU Controlled Variable Voltage Alternators varies from over 15 volts to 12.3 volts or even zero whilst driving. These present a new and different set of problems particularly if associated with the regenerative braking described below.

Regenerative braking

A vehicle in motion has a great deal of kinetic energy. This is substantially lost (as heat) whilst braking, and also during prolonged deceleration (as being slowed down a steep hill). The vehicle's computer system detects all such deceleration and, by boosting alternator's output to over 15 volts, force charges the starter battery.

This battery is normally charged to only 80% or so, thus providing 20% storage capacity. The boosted alternator energy rapidly brings the battery to 100% charge.

Typical Euro 5 alternator - note the large pulley size. Pic: original source unknown.

The now acquired 20% battery energy then powers the vehicle's electrics until the battery falls again to 80%. Meanwhile alternator voltage is reduced to about 12.3 volts - or the alternator is shut down altogether.

A plus 15 volt charge (at up to 200 amps) wrecks lead acid deep cycle, AGM and gel cell batteries. This precludes directly paralleling them across the starter battery whilst charging.

Further, that 12.3 volts (or zero) negates using a voltage sensitive relay to isolate the auxiliary battery. Were one to be used with such an alternator, whenever the output voltage drops below about 12.7 or so volts (which is most of the time) that relay opens for a typical two-three minutes. This would preclude auxiliary battery charging altogether.

Many post-2013 vehicles have such alternators, and also regenerative braking. If the engine is Euro 5 or 6 (onwards) compliant it will almost certainly have one.

Vehicles known to be affected currently include: BMW X5 post 2010, Ford Ranger post 2011, Grand Jeep Cherokee post 2013, Holden Commodore VE onwards, Hyundai Santa Fe Fe post 2010, Land Rover Disco 4 onwards, some models of Mazda BT50 2011 onwards, Mazda Spirit post 2012, Mitsubishi Pajero post 2012, Nissan D40 Navara post 2011, Nissan R51 Pathfinder post 2011, Nissan Patrol V8 post 2012, Range Rover 4 post 2011 and Subaru Forester post 2012.

Identifying alternator type

If the alternator type is not revealed in the vehicle's specifications, it can be established by monitoring the voltage across the starter battery via a voltmeter or multimeter with extended leads. Secure the leads as they tend to get caught up in the fan belt. Then drive at varied temperatures, conditions and loads (such as the air conditioner). Make a note of the lowest voltage encountered. If ever below 12.7 volts it's odds on it is a variable voltage alternator.

See also https://www.redarc.com.au/calculator/dual-battery-calculator

Overcoming alternator problems

Fixed voltage and temperature controlled alternator charging issues are fixed by using dc-dc alternator chargers. Auxiliary batteries thus charge whenever the engine is running regardless of alternator output voltage as long as that *never* falls below 12.7 volts whilst driving. The starter and auxiliary batteries are isolated by a voltage sensing relay below that voltage. The mode of auxiliary battery charging is thus determined by the dc-dc alternator charger, not by what the alternator produces. Dc-dc chargers also assist to overcome voltage drop by locating them close to batteries at distance from the charging source.

Battery-to-battery dc chargers

Variable voltage alternators require a variant of the above. They use the starter battery as a voltage reference to determine when and how to charge the RV's auxiliary battery, and when to separate the starter battery from the auxiliary battery. They cannot use a voltage sensing relay to do that as such relays drop out at about 12.6 volts: higher than a variable voltage alternator's often 12.3 volts or less.

As with dc-dc charging, battery-to-battery dc charging accepts the variable alternator voltage output and boosts or reduces it to maintain a stable output using the charging profile that best suits the capacity and type of auxiliary batteries. It does so, as with most upmarket mains battery chargers, in a generally similar manner as shown below. See also page 26.

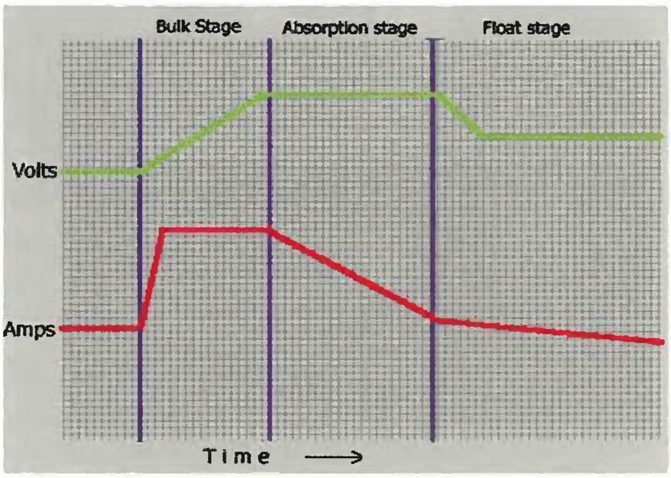
Stage one (boost)

Charging lead acid, gel and AGM batteries is done in stages. During the first (boost) stage, as battery voltage rises, so does charging voltage. This constant voltage difference is automatically adjusted to ensure that, within the maximum current capacity of the charger, the charge current stays at the highest rate that is safe for both the battery and for the charger itself.

If the charger is large enough relative to the battery, that highest safe rate is typically 15%-25% of the battery's amp-hour capacity. This stage typically brings the battery to 70%-75% of full charge.

Stage two (absorption)

In this stage, charging voltage (and hence charging current) is usually reduced such that the battery charges at a constant 10%-15% of amp-hour capacity. This is typically



The basics of multi-stage charging: different products have minor variations but the general principles and intent are similar.

for up to two hours or so enabling the charge to become evenly distributed throughout the plates and electrolyte. If a heavy load is applied during this period, most such chargers revert to their boost cycle.

Stage three (float)

Following absorption, charging is reduced such that it counterbalances battery internal losses and minor constant loads (e.g. electric clocks, security alarms). This so-called 'floating' is at a voltage dependent on battery type and (ideally) temperature. It is typically 13.2-13.8 volts for conventional batteries and 13.2-13.6 volts for AGM and gel cell batteries (the lower voltages typically apply to high temperatures).

At this stage, a battery is likely to be 95%-100% charged. As long as the float voltage is correct and water level (if applicable) checked from time to time, conventional lead acid batteries may be left floating indefinitely, but many AGM and gel cell makers prefer their products to be differently treated.

AGM batteries have minimal internal leakage. As noted previously, they retain about 60% charge for a year or more in temperate climates. Gel cell batteries do not totally equal that retention, but some are close to doing so. Because of this, even minor float charging (either) may be *overcharging.*

Many AGM battery makers suggest that users planning to lay up their vehicles should fully charge the batteries before storage, and recharge them at about six month intervals in hot climates, and every 12 months where it is mostly below 25^{0} C. Batteries charge at a lower voltage when hot.

Some chargers have an (optional) function that automatically corrects the charging rate for temperature variations.

Equalisation

Now less used, this usually manually-selectable cycle pumps current through the fully charged battery at up to 16 volts for an hour or two. Its intent is to overcharge to ensure all cells have equal voltage. Whilst possibly desirable for the typically 24 series-connected two volt cells in 48 volt stand-alone property systems, many battery makers say it is neither necessary nor desirable with today's battery technology. It is best to not use this (usually optional) cycle unless the battery maker specifically recommends it.

Charging lithium-ion batteries

Discussing this is currently complicated by a lack of agreement between many DIY users (and some installers) regarding charging. Many advise to limit it to 80-90%. The battery makers however, and commercial (LiFePo4) lithium-ion battery charger makers advise to charge very close to (or reach) 100%.

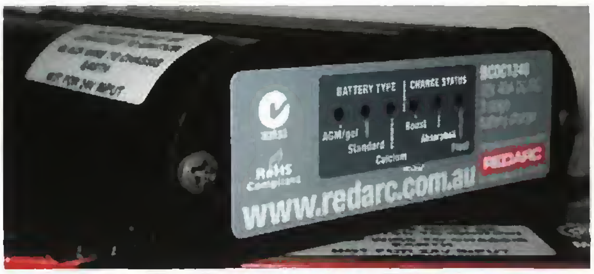
What is agreed is that overcharging destroys or badly damages these batteries. The complication in avoiding this is that there is only a tiny difference between full charge and overcharge.

All require the cell management system mentioned in page 22.

Right now I only recommend using these otherwise excellent batteries if you have them installed by a company that truly knows how - or you *truly* know what you are doing.

Choosing a battery-to-battery charger

To suit various types of alternators, Redarc (for example) has a standard range of such chargers for vehicles where alternator voltage *never* falls below 12.7 volts whilst driving.



Redarc BCDC 1240-LV will handle 40 amps from ECU controlled variable voltage alternators. Pic: redarc.com

The company's LV variants cope with variable voltage alternators and provide specific battery charging algorithms to suit lead acid, gel, AGM and calcium batteries. Some also accept solar input.

These units overcome the limitations of various alternator voltages, and fixed voltage charge cycle.

They are arguably the only charging methods (for auxiliary batteries) now worth considering.

Adding solar

Many people wish to run a large electric fridge or fridge-freezer (see pages 34-37 re this). This is feasible via solar for big motor homes, fifth-wheel caravans and coaches that have sufficient space for the substantial solar array required but back-up alternator, fuel cell, or other auxiliary charging is advisable. An alternative is to use a T-rated fridge that runs from solar and the alternator whilst driving, 230 volts when available and LP gas at all other times. Doing so slashes solar and battery capacity. (See page 56.)

By and large, there are no major problems if you wish to use both alternator and solar charging simultaneously and for several hours each day. It does not work as well as might be expected because, beyond 50% charge, the battery charges mainly from whichever source provides the higher voltage at any time. As the draw from one source goes up, the other goes down.

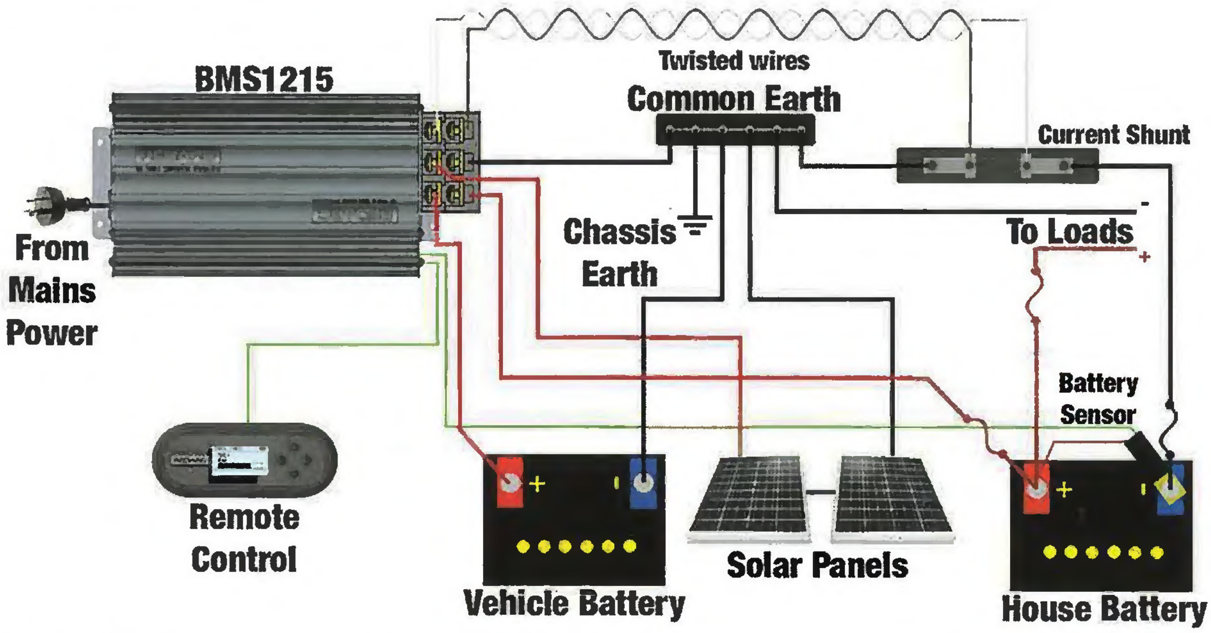
Whilst people tend to worry about doing so, it's fine to connect the output from a solar regulator directly across the RV's auxiliary battery despite it being also alternator charged.

Need for buying caution

Many low-end 230 volt battery chargers are sold as multi-stage chargers but are not. They charge at about 14.4 volts and should turn off when the battery reaches that voltage. Not all do. Many a costly battery has its life shortened by this. Good chargers are costly, but this is not an area for skimping.

A good charger is programmable for the batteries you intend to charge, e.g. conventional lead acid, sealed lead acid, gel cell, AGM etc. A good three-stage 15-20 amp such charger will outperform 30-40 amp constant voltage chargers once beyond 40% or so charge.

If planning to be extensively away from mains power, stand-alone solar necessitates daily solar input to be, on average, at least 15% more than that used, preferably 25%. Later sections of this book show how to assess the feasibility.



How the BMS 1215 is typically installed. Most interconnections are made within the unit itself. Drawing: redarc.com

Installation hint

A voltage sensing relay cannot be used with variable voltage alternators. Further, current sensing in such a vehicle's electrical system is achieved by measuring voltage drop across the main battery negative to vehicle chassis cable (it is sometime a Y cable with feeds to both starter and alternator.) That cable must not be interfered with in any way. All added electrical accessories *must* be grounded to the vehicle chassis or body, not to the starter battery negative terminal.

Generators & fuel cells

The most usual need for a generator in an RV or cabin's solar electric system is to run an electric refrigerator when battery energy is low. Even if you have a coach roof full of solar modules, a generator is also necessary if you need air conditioning all night.

It is also advisable to use a generator for large infrequent loads such as clothes dryers (if run on a 'hot' cycle), and large power tools, or to limit their usage to where there is mains power.

There is also a case for generator charging for RVs that spend only the odd winter month or two in cold areas. It is not worth increasing the solar and battery capacity otherwise unneeded for the rest of the year.

Most small petrol-electric generators provide 230 volt ac. Many also produce about 13.2 volts dc at an industry common eight amps for directly powering 12 volt devices but, even if *labelled* 'battery charger', most are unable to bring a battery much beyond 50% charge.

Honda inverter generator produces up to a constant 2700 watts. Noise level is 58 dBA at 7 metres at its rated load. Pic: Honda.

This is rarely disclosed by vendors so generators plug away all day long in costly and pointless attempts to increase that charge.

A *few* generators though, including the relatively quiet Honda inverter range, have a higher dc voltage and may overcharge.

Honda states (albeit confusingly) 'the output can charge batteries - but is not a battery charger'. The company recommends charging only to 50% - but that state of charge is hard to assess.

With *all* such generators it is far more effective and safer to use a high quality mains voltage charger plugged into the generator's 230 volt outlet.

Be aware that some switch-mode chargers and other electronic devices may not operate satisfactorily from cheap generators. They may even be destroyed by them.

Always switch off electrical equipment before a basic generator runs out of fuel. When this happens the generator tends to 'splutter' to a halt.

The resultant rapid speed changes generate high voltage spikes that may damage the generator and whatever is connected to it at the time. This problem does not affect inverter/generators.

The late 215 released TEC 29 from Dometic that produces 2600 watts. With a sound level of 54 dBA at 7 metres (at 75% output) it is exceptionally quiet.

The unit is claimed to use 1.2 litre/hour of unleaded petrol at maximum output.

All such inverter generators work well with switch-mode chargers.

The 2015 released Dometic TEC 29 petrol generator. Pic: dometic.com

Diesel/LPG generators

Quiet diesel generators are rare and costly. Onan makes a good 5.5-kVA diesel unit suitable for large RVs and cabins. Onan and others also produce LPG-fuelled versions of their petrol-engined units.

The more costly generators have remote stop/start facilities. These can be interfaced to a solar or other regulator to operate automatically when the battery and load demands.

Whilst handy, it is annoying to have a generator starting up automatically in the middle of the night. The complexity also complicates fault-finding.

This Cummins-engined Onan QG 280 generator runs on LP gas. Noise level is 70 dBA at 3 metres. Pic: Onan.

Fuel cells

Fuel cells convert fossil fuels such as methanol, petrol, diesel, LP gas etc into hydrogen. This enables electricity to be produced electro-chemically. Unlike generators, there is no thermal burning process, no noise, and next to no pollution.

Large fuel cell systems have been in use since the very first space craft, but many cost hundreds of thousands of dollars. Some cost millions.

Fuel cells are effectively 24/7 power supplies that, unlike generators, use fuel roughly proportional to the load. A battery is required to cope with peak loads greater than the fuel cell's maximum.

For most applications a smallish starter battery is likely to suffice (long term battery storage is not required). Because of their ability to deliver high current, lithium batteries too make ideal such partners.

The most potentially promising fuel cell was Truma's LP gas powered VeGA 12 volt unit. It produced 23 kWh from a 9 kg LPG cylinder. It was initially announced as being available in 2007, but this became 2008, 2009, 2010 etc. It surfaced in late 2012 but (at a company subsidised 10,000 or so Euros) failed to find enough buyers. All sold will have ongoing service, but production ceased in late 2014.

The only small fuel cell currently (August 2016) on the market is EFOY's range of methanol-fuelled units. They are of varying outputs (and also available to military specification). They originally cost $3500 upwards but now cost well over twice that.

Most are about the size of a jerry can, and weigh only a few kilograms. They generate five or so amps upward (at 12 volts dc) and can be run 24 hours a day if required.

These units are an effective and silent back-up for solar. For most people, however, their initial price and high fuel cost may rule them out as a major source of electrical power.

Whilst this book has suggesting this since 2006, (and it has yet to happen) if/when prices fall, fuel cells are likely to wipe *noisy* generators off the face of this planet. Meanwhile, solar and the relatively quiet petrol-fuelled generators are the only viable alternatives.

The EFOY Comfort fuel cell outputs 6 amps at 12 volts. It weighs 7.5 kg. Other sizes are available. Pic: EFOY.

Inverters

Many people buy a big inverter primarily to drive a microwave oven. Then, having 1500 watts or more available, use it to run appliances like small blenders, coffee grinders etc. Microwave ovens that run from 12-24 volt dc are available, as too are TVs, DVDs etc. All such, however, are 230 volt units with an inverter inbuilt, or supplied for the device to plug into. There is little point in buying an often more costly 12-24 volt dc appliance, if you have (or plan to have) a 230 volt inverter anyway. If you don't need a microwave, most small appliances readily run from a good 350-500 watt sine-wave inverter.

Inverter types

There are two main types of inverter output. They are square-wave, or misleadingly called modified square wave or 'simulated sine-wave'. Or they are sine wave.

Powertech 180 watt inverter has a 300 watt peak. Jaycar Electronics (Cat. MI-5700). Pic: jaycar.com.au

Early square-wave inverters drove most appliances of their (1960-1970s) era but were extremely inefficient. The later modified square wave versions will drive some, but not all electronic equipment. They may damage some (particularly laser printers) and may cause an annoying hum on radios, TVs and motors. They can cause motors to overheat.

Modified square wave units are still made. Quality ranges from good to dreadful. If buying one, choose only the best.

A true sine-wave inverter is *strongly* recommended because it produces clean mains-equivalent power.

Today's best sine-wave inverters consume only 5% more power than that of the applied load. Most sense current draw and switch themselves to a very low current standby mode when they sense no load. Some however remain fully working even if the load is tiny and draw a higher overhead current (a few watts) constantly. This is hugely inefficient if the only load is (say) a 230 volt clock. A battery clock is the obvious solution.

Transformer- based inverters

Apart from sine wave and modified square-wave, there are two main ways of designing and building inverters: transformer or switch-mode.

Transformer-based inverters are like silicon donkeys. They'll carry a heavy load briefly, a medium load for longer, and a comfortable load indefinitely. If you don't know about inverters (or donkeys), you are likely to choose one bigger and more costly than you really need.

Most transformer based inverters can maintain twice or more their rated output for some seconds, and 130%-150% for up to 30 minutes. These are not 'overloads' as such. The ability is simply a characteristic of an iron-cored transformer. The inverters' other bits are cheap. It costs very little more to scale them to provide that peak output.

Transformer-based inverters are *intended* to work this way. If truly overloaded they are still not damaged. As with donkeys, they stop working for a time to cool off. Inverters' power/time characteristics are usually shown in their makers' literature. When running continuously at full load a transformer-based inverter is unlikely to be tossed by the added short term load of a small blender or coffee grinder etc.

Select an inverter that copes with the heaviest energy-drawing appliance you will run. This is often an electric motor as these draw up to three times their running current for a second or so whilst starting. Include only other appliances that are *likely* to be run at the same time, not those that just *might* be.

An inverter's output (wattage) can be limited by cable voltage drop and the battery's ability to deliver the current involved. Because they can briefly supply up to twice their rated continuous load, a 12 volt, 1500 watt such inverter may draw 250 amps. This requires starter motor size cable, at least a 300 amp-hour AGM battery bank, or a LiFePO4 lithium-ion battery (see page 23) to supply it.

Whilst 12 volt 2000 watt inverters are made, most inverter makers recommend a maximum of about 1200 watts for 12 volt inverters, 2400 watts for 24 volt inverters, and 4800 watts for 48 volt inverters.

A 150 watt transformer-based inverter will drive a radio, TV, VCR, DVD, and small appliances, but not if several are in use at the same time. A 250-350 watt inverter is often a better buy. Inverters that size will run small power tools for short periods, but 500 watts is more comfortable. A 230 volt microwave needs a 1500-1600 watt inverter, and more solar and battery capacity. You can run most washing machines (on their cold cycle) from a 250-350 watt such inverter.

On a larger scale, the 48 volt SEA Everest inverter (right) produces a continuous 3.8 kW and has a peak surge capacity of 11 kW. This is enough to start and run large electrical machinery, even big air compressors (that start up on virtually full load).

This SAE 3.8 kW unit can produce short peaks of more than 11 kW. Pic: Author.

Switch-mode based inverters

Switch-mode inverters use a solid-state transformer-less technology. They are smaller, cheaper and very much lighter, but none has the 'overload' capacity of good transformer-units. Most, even those higher priced, are rated at 80% of their claimed output if run for more than a few seconds. Care is required when buying. Some are limited to 50% or even less.

These inverters can be an excellent buy if overload capacity is not required, but if it is, they must be scaled accordingly. If high overload capacity is needed, buy one that is transformer-based.

Paralleling inverters

Some inverters (such as those from Outback Power) can be parallel connected to increase capacity. If you have this in mind make absolutely sure the units really *do* have this capability. Do not take a sales person's word for this. Only a very few brands of inverters can be used in this way.

Four paralleled Outback Power inverters. Pic: Outback Power.

Wired in - or freestanding

Many small inverters such as the Powertech unit (page 30), have one or more socket outlets. Appliances only may be plugged into those sockets.

It is seriously illegal and extremely dangerous to have such inverters connected to any fixed mains voltage wiring. There is a very real risk of severe electric shock. Inverters connected into fixed mains voltage wiring are made specifically for this purpose.

Automatic load sensing - phantom loads

As noted above, many small inverters actuate when a light or appliance is switched on. They revert to a low energy mode when the last load is turned off. This useful behaviour can be foiled by 'phantom loads'.

Most pre-2014 (and some privately imported appliances) (e.g. TVs, dishwashers, washing machines, most computers and computer printers, DVDs players and even some blenders) draw a continuous 4-20 watts if switched off only at the appliance.

The pre-2014 little black boxes (wall warts) that plug into power outlets also draw much the same energy - in some cases whether the appliance is switched on or not. This applies also to appliances with remote controls if switched off *only* by those controls. Some, if pre-2014, draw 10 watts or more (about 0.25 kW a day). Such loads will convince an inverter that an appliance is still on, preventing that inverter returning to stand-by. This results in a double loss: that of the energy drawn by each phantom load, plus the energy drawn by the inverter's internals through being kept fully working.

This energy/power meter from Jaycar plugs into the power socket via the cord. The unit to be tested is then plugged into the meter. Pic: Jaycar Electronics.

Some inverters *can* be set to respond only to loads larger than phantoms but this may prevent them responding to wanted small loads, like an electric razor, unless (say) a light, is turned on at the same time.

Manually switched inverters are still available but it is only too easy to forget to switch them off after use. On the whole it is better to have an automatic load sensing unit and, if adjustable (as most are), to spend some time setting it up.

Post-2014 approved appliances are legally limited to such draw being less than 1 watt - but that's still an unacceptable waste in a cabin or small RV, let alone the 30 or so such loads in many homes.

Consider buying a 230 volt power energy meter not just for RV use but also around the home. They can be obtained for about $20 or so but Jaycar's MS-6119 is well worth its (2016) $34.95.

Safety - a buying consideration

Safety, as well as monetary cost is involved. Cheap inverters may not electrically isolate the 230 volt output from the input. This can result in a high voltage being imposed across one side of the battery. As electricians will appreciate, this can be dangerous in certain circumstances.

Most high-quality inverters have their output fully isolated from their input. Reputable vendors explain why, and manufacturers make a point of clearly advising (in the sales literature and on the units) that their products *are* electrically isolated. As a general rule, unless there is *specific* evidence of electrical isolation, it's probable there is none.

Partially because of the above, there is a wide range of price for what may at first seem identical inverters, but are not. Good 150-500 watt electrically-isolated sine-wave inverters cost $1.00-$1.50 per watt. From thereon, price per watt progressively falls. Non-isolated inverters are a lot cheaper - but it is easier to replace dollars than to replace yourself.

A really good quality modified square-wave inverter will drive *some* loads, but far from all.

Unless you know what you are doing buy only a good quality electrically isolated sine-wave unit. (If you *truly* do, you are unlikely to buy one anyway.)

There are only a few good inverter makers. Avoid hardware store specials. Stay with known brands and buy only from reputable long-established vendors.

If the inverter is to connect into 230 volt wiring, obtain *written* assurance that this can be done legally as well as technically. As emphasised on the previous page, most small inverters (those with inbuilt outlet sockets) must not legally be connected to such wiring. If they are, the resultant system is likely to be potentially (and often actually) dangerous. There is, in some circumstances, a real risk of electrocution.

Don't take a salesperson's word that an inverter is double insulated and/or electrically isolated. A few sales people may well have the technical background to understand what you mean but these are rare.

Refrigerators

The two main types of RV fridge are top opening and door opening. Those made specifically for RV use, and often used in cabins, have relatively efficient 12/24 volt compressors. These fridges originally drew less energy than most domestic fridges. There are however now several 230 volt ac domestic fridges of 220-250 litres that draw much less.

Three-way fridges, that run on LP gas, or 12/230 volts when available, use the less-efficient absorption cycle but are still well worth considering as they hugely reduce the need for solar and battery capacity.

Top or door opening?

Cold air sinks and flows out of a door opening fridge, but as air is a poor conductor of heat, the loss of energy is not that high. If the fridge is opened frequently however (as may happen with young children around) that loss can be substantially reduced by using high fronted plastic drawers. Keep the fridge full but not tightly packed. Use plastic bottles full of water if necessary.

Because cold air does not rise, none escapes when opening a chest fridge. Such fridges are thus slightly more efficient. Murphy's Law (of selective gravitational migration) however results in the most needed items being in the least accessible place. This necessitates a lot of cold items being taken out and repacked. Water condensing in the bottom needs frequent removal. The bottom also gets mucky.

This is less of a problem for chest freezers but can be one for chest fridges and fridge/freezers as these are accessed more frequently.

Electric-only

Many electric-only fridges are made specially for caravans and motor homes. A 75-80 litre chest fridge or fridge/freezer really needs two 100 watt solar modules for that purpose alone.

Despite RV) vendor and occasional owner claims to the contrary, door opening RV fridges of 170-220 litres need three by 120 watt modules for *reliable* use in hot places. This is particularly so up north where it's hot all night too.

A few larger 12/24 volt door opening fridges are specialist-made, but most are converted standard domestic units. The former are preferable as most RV fridges have thicker heat insulation.

Electric-only fridges run from the vehicle's alternator whilst driving (via a relay operated by the ignition), and from auxiliary battery and/or solar power when not. Most run well from solar.

Engel 75 litre chest fridge/freezer. Pic: Engel.

As with all fridges, energy consumption varies hugely with the nature of installation, usage and ambient temperature. In practice very few are installed as their makers intended and, as a result, do not perform as well as they should.

A 12/24 volt electric fridge can almost always have its cooling ability enhanced and energy consumption reduced by correct installation. See pages 81-82.

Most electric-only fridge/freezers draw about 1 amp-hour/day per litre of volume. Fridge-only units draw about 0.8 amp-hours/day per litre. Large fridges use proportionally less. Fridges with the recently introduced variable speed motors are claimed to draw up to 25% a day less.

Eutectic fridges

This type of electric fridge uses a eutectic-like low-freezing-point liquid that freezes within tanks that form the walls of the fridge. Their recommended usage is initially to 'pump down' by running the fridge at its coldest setting for eight to ten hours.

Once that is initially done, the fridge then typically needs to be run for only one or two hours each morning and evening.

In cold places it may need to be run for an hour or two every second day. In very hot places, pumping down may need repeating from time to time.

Eutectic fridges may, if wished, be left to run on a fixed thermostat setting, but if that is done their consumption and performance will be much the same as a conventional fridge.

Dometic three-way fridge. Pic: Dometic Australia.

Until recently (when used, in their pump down mode) eutectic style fridges used less energy than a conventional chest fridge of similar volume.

This energy saving is not so much due to the eutectic principle but, as a pump's start up current is about twice that of its running current, to the compressor pump not constantly cycling on and off in pump down mode.

The more recently introduced constantly-running variable speed compressor units typically use 25% or so less energy than before. The eutectic units' main benefit now is that (in pump-down mode) they do not have to be run at night.

Autofridge makes chest type eutectic units (a new model is expected in late 2016). Indel (Italy) makes eutectic door opening units.

Three-way fridges

Three-way fridges run from the vehicle's 12 volt system whilst driving, 230 volts when available, and gas at all other times. They draw *far* too much current (10-25 amps) to run from solar energy.

Historically at least, three-way fridges tended to have a poor reputation. This is partly because most sold prior to the later 1990s were not designed to be used in ambient temperatures exceeding 25° C, but this was rarely known by sales staff, let alone buyers.

Further, their performance was often degraded by seriously incompetent installation. If well installed they coped well enough most of the time, but could not handle semi-tropical heat.

T-rating

This situation changed in the 1990s. The European Union (EU) introduced a Standard for fridge cooling performance that included four graded levels of ambient temperature performance. The T-rated range versions work well even in Australian heat waves.

All such EU-rated fridges have a compliance plate that contains the notation 'Climate Class'. To the right of that notation will be found any of the letters SN, N, ST or T. These, respectively, are abbreviations of Sub Normal, Normal, Sub Tropical, and Tropical. The SN and N are designed for ambients up to 32° C, ST up to 36° C, and T up to 43° C.

Don't confuse 'T-rated' with the term 'tropicalised'. All Dometic fridges sold in Australia have been marketed as that following an upgrade to their specifications in the late 1990's. Dometic used the term 'tropicalised' accordingly. The term 'tropicalised' is *not* the same thing as 'T-rated'. Dometic *never* claimed it is, but far from all sales-people and owners seem aware of this. Unless the fridge has a EU compliance plate that *specifically* states a fridge is 'T-rated' it is not.

The choice

Early editions of this book suggested that 110/120 litre fridges are the largest economically practicable for running mainly from solar. Since then both fridges and solar modules have become more efficient. The latter are now very much cheaper per watt.

Many medium-sized caravans and motor homes settle for 170 litres, larger ones tend to have 220 litres or more. Camper trailers typically have 60 litres, with 80 litres as the realistic upper limit for solar on the trailer or tow vehicle alone. Anything larger is likely to need solar modules on each.

Most users find electric-only fridges more convenient to use than three-way units. If solar module space allows, an electrical compressor-type fridge suits most applications. All are likely to use 65-70% of the total daily electrical energy usage of most RVs.

Never buy two or three fridges of small volume, rather than one of their combined volume. This is because a fridge's cooling loss is mainly via its outer cladding. The area of that cladding however is not linear with volume. As a result those three small fridges will draw up to twice that of one of the same volume. (A few quick sums may surprise.)

Three-way fridges cost more initially. Medium sized units use up to 0.4 kg of gas a day. Some three-way fridges switch automatically between gas and electricity, but that switch too gobbles energy all the time.

Eutectic fridges are efficient on their pump-down mode, but take all day to drop from ambient temperature to zero the first time they are used that way. This is not a problem for long term travellers, but can be inconvenient if the fridge is used only occasionally.

They *can* be run on a low thermostat setting but, as noted previously, they then draw much the same energy as other fridges of the same size and age.

A eutectic fridges' big advantage is not needing to be run at night. This can be a considerable bonus for light sleepers as constant cycling of even the quietest of conventional fridges can be disturbing whilst trying to sleep.

The variable speed compressors now used in some conventional compressor fridges are quieter, but may still disturb.

Correct installation

As stressed throughout this book, all fridges need to be competently installed, yet few are. If they are not, an electrical compressor fridge may still perform well enough, but cycle on more often and for longer - and thus draw a lot more power to maintain that performance.

Three-way fridges however cannot compensate that way. Unless properly installed, as shown on page 81-82, they are not likely to perform as they should. But, if installed correctly, today's three-way EU-rated fridges really *do* work as specified.

Lighting

Mains voltage incandescent globes were banned from sale in Australia (in 2011), and many other countries. They produced more heat than light and, except for short-span use, were too inefficient to be driven from solar energy. They are still available in 12/24 volt form but as more efficient alternatives are now available there is little point in using them.

Regardless of the lighting source, a great deal of energy can be saved by painting walls white, or in a light reflective colour. Beige (particularly), and teak/walnut veneer, suck light like a spectral vacuum cleaner, absorbing three or four times as much light as does white.

Switching

Internal lights are best switched individually from close to where they are located. External security lights need switching from two places. One switch should be readily accessible during the evening, the other from where it can be reached from the bed. Banging and coughing is usually due to nocturnal animals hunting down accidentally left-out Tim Tams or Camembert, but it's good to be able turn the outside light on to confirm that without having to get out of bed.

Halogen

Whilst no longer recommended, halogen globes are still legally on sale. They are tiny incandescent bulbs filled with a gas that enables them to run at extremely high temperature. They are made in 12 and 24 volt form with outputs from 10-50 watts. The 50 watt versions generate a great deal of heat and some require special large-pin holders. Care must be taken that the heat they generate can readily escape - this is a known fire hazard.

Fifty watt halogen - a lot of light, but also heat.

Twelve-volt halogens are intended to run at 11.8 volts. They burn out quickly above 13.0 volts so don't use them whilst battery charging.

Bare halogen globes plug into basic holders. Others, called 'dichroics', have integral reflectors available in various angles of spread, from about 12 degrees to 60 degrees. Halogen globes generate ultra-violet but this is effectively blocked by glass. Dichroic globes usually have a glass cover but bare globes really need the same - not least as they can inflict a serious burn.

Halogen globes provide usefully focused light but draw far more power than light emitting diodes (LEDs). Ten or twenty watts is fine for reading, but fifty watts may be needed for close work.

Halogen lighting has been an effective but essentially interim technology. Whilst halogens are still used in homes and particularly showrooms, the LED lighting described later in this chapter is the only main lighting technology to consider for both new and updating existing vehicles. Likewise domestically.

Mains voltage fluorescent lights

Fluorescent lights use half the energy of halogen lights, but need 230 volts to drive them. They use about half the energy of halogens that produce the same amount of light. Warm-white tubes and globes have a pleasant glow, similar to incandescent globes.

Standard fluorescent tubes flicker slightly and can annoy, but most people have to deliberately look for it. Compact fluorescents have inbuilt frequency-raising that increases efficiency and eliminates visible flicker. They range from five watts upwards. The fifteen watt version produces much the same light as a 230 volt, 60 watt incandescent.

Fluorescent lights give a wide, even spread of light. Their placement is thus not critical, but that spread implies that light may be directed where it is not necessarily needed.

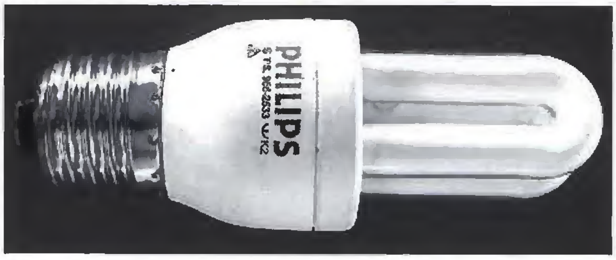
Twelve volt fluorescent lights

Twelve-volt fluorescent lights are 230 volt items with inbuilt inverters. The earlier cheaper units had a harsh white output, and some generated a lot of radio and TV interference. Higher quality low-interference units have long been available. Some have warm-white tubes. They are also made in compact fluorescent versions.

Compact fluorescent globes are often promoted as having 'extra long life' - but that life is shortened by frequent switching.

A small percentage fail within the first hour or two but most last for years. Test new globes for a few hours immediately after buying and return any that are faulty.

These globes are made in both Edison screw and bayonet fittings. Use the screw type for mobile use.



This is a 10 watt warm white compact fluorescent. Efficient and effective, but a little bulky for smaller RVs.

Light emitting diodes

Most lights based on LEDs provide a focused beam - from 15° to 140° or so. They are ultra-economic and especially effective for lighting discrete areas such as kitchens, cooking on campfires, reading etc. Providing the areas have light colours, reflected light provides effective background illumination. They are now readily available in a vast assortment of shapes,outputs and colour temperatures.

This 5-watt LED fits the standard (MR16) halogen globe holder - it has about the same light output as a 20 watt halogen globe.

There is a wide range of 12 volt LEDs in both warm white (about 2700° - 3100° Kelvin) and also daylight white (5000°-6000° Kelvin). The MR 11 is 35 mm diameter with pins 4.0 mm apart. The MR 16 is 51 mm in diameter and has pins 5.3 mm apart.

The fine pins of these LEDs tarnish after a time. If they stop working, cleaning the pins with fine emery paper or the side of a matchbox usually revives them.

There are also 230 volt LEDs that look much as the 12 volt versions but have GU 10 bases (larger two-diameter locking pins); or much physically larger, and with Edison screw or bayonet type fittings.

Retail prices are still high, but whilst LEDs can be bought for typically a third of the retail price on many Internet sites, most of the ultra-cheap ones are very inefficient and have proved to have a short life span.

This is a major consideration for those that have multiple hard to reach ceiling lights.

Direct LED replacement for 230-volt incandescent Edison-screw base globes.

Light output

Until the advent of LEDs people somehow 'knew' the light output from (say) a 50 watt incandescent globe - not least as there would be next to no difference between brands. Much the same was true of halogen globes.

LEDs however are very different. Light output (for the same watts) varies over a range of at least 3:1. Because of this a high quality 5 watt LED is likely to produce a lot more light than that of a 10 watt eBay cheapie - and last far longer. Their light output is usually conical with angles from 15-140 degrees.

The related unit is the lumen. Most LED maker disclose the lumens per watt. Light fitting suppliers are well aware of the confusion regarding this. Most have displays enabling comparisons to be made.

Light fittings for RVs

Any number and style of affordable LED light fittings for RVs are readily available. Some are direct LED replacements for existing fittings.

Many people have hand-crafted affordable and effective general LEDs lights using existing light fittings. An elegant example, made some years ago by Lawrie Beales, is shown below.

ReNew magazine (a quarterly available from most newsagents) has various project kits that enable large wattage white LED light fittings to be built for a small fraction of the cost of commercial offerings.

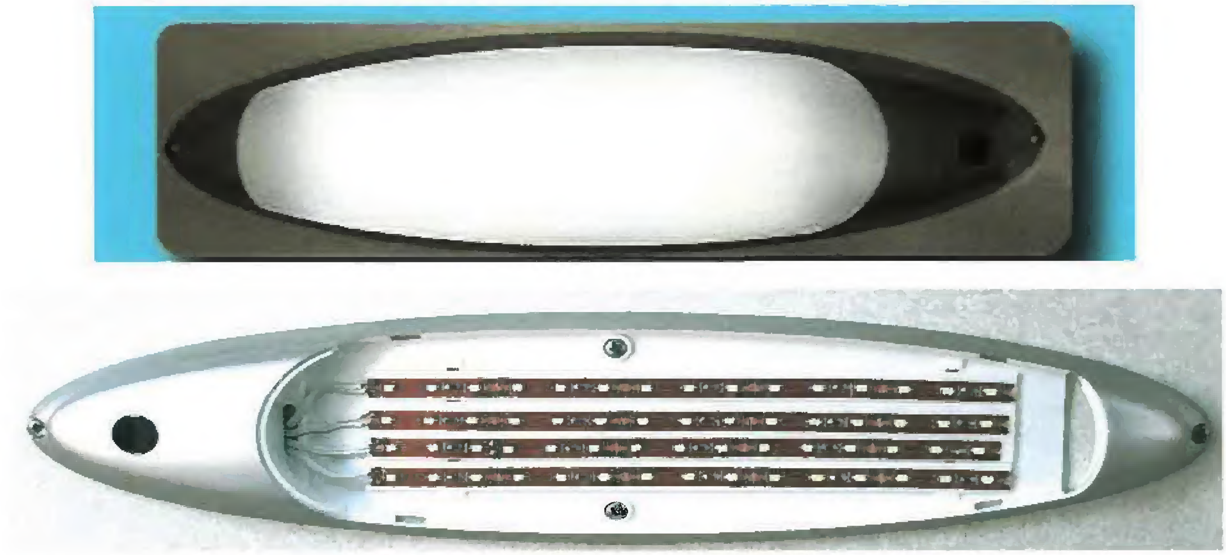
Silicon Chip magazine carries associated helpful articles and LED constructional projects. Components are available from Altronics, Jaycar, Oatley Electronics etc.

The choice

As noted elsewhere in this book, extra-low voltage wiring (e.g. 12-24 volts) is simple and easy, and you can legally do it yourself.

For lighting, my strong recommendation is for warm white LEDS. Their energy draw is so small that, if the cable is strong enough mechanically, it will be adequate to carry the required current. The readily available 1.5 mm^2 is electrical overkill but any smaller lacks adequate mechanical strength for RV use.

LEDs are thus a practical and convenient alternative in those only too many RVs where the existing cabling is thinner than desirable. You can always tell if such cabling is inadequate: lights already on dim discernibly when another light is turned on.



Top: This elegant LED light fitting was crafted by Lawrie Beales.
Below: multiple LED lights in strip form provide good well evenly spread illumination.
Pix: Lawrie Beales.

Water & pumping

Water pumping from solar is rarely a problem in caravans and small motor homes, but it can become so in big motor homes, coaches and cabins. With these, water may needed in largish volume and pressure for washing machines and dishwashers. It can also be a problem if water is needed for irrigation.

Use 12 volt or 24 volt pumps for volumes of less than 1000 litres a day. These draw less energy than most 230 volt pumps, although high efficiency such units (usually variable speed) are now available.

For large cabins etc consider using use the very efficient 24 and 48 volt pumps with brushless dc motors made by Lorenz and others, but rarely stocked by plumbing and irrigation suppliers.

It is *essential* to match pump type and size with the specific usage. Get this wrong with most mains voltage centrifugal pumps and energy usage soars.

Seek specialised advice from the makers or knowledgeable vendors, stressing that low energy draw is essential.

Make	Volts	Amps	Flow L/min	Pressure kPA (psi)
Flojet 4405	12/24	3.9 (12 V)	11	137 (20)
Flojet 4325	12/24	6.3 (12 V)	14	137 (20)
Jabsco 44010	12	4.0	9.5	133 (20)
Jabsco EF0612	12	6.0	12.5	133 (20)
Whale EF0612	12	3.9	7.0	212 (32)
Whale EF0012	12	4.2	10	212 (32)
Jabsco 36800	12	6.0	12.5	22 (20)

Typical performance including energy draw. Starting current is typically twice the running current, cabling needs sizing accordingly.

Water pumps for RVs

The most commonly-used pumps in the cheaper camper trailers and caravans are of small in-line cylindrical form. As they lack self-priming, they must be within the tank or located externally below the lowest tank water level. They are cheap and simple, but lack adequate pressure.

A more satisfactory (albeit noisier) pump is the diaphragm type. These can be mounted above the tank's water level, but may need a one-way valve in the pipe between the pump and the tank to ensure reliable operation.

These pumps are reasonably reliable if used frequently but tend to stick if not. It is advisable to carry a spare pump diaphragm.

The most basic pumping systems require an associated switch to turn the pump on and off. This switch may be located close to the associated tap - or may be part of the tap itself. Such systems are cheap, simple and effective but, as switches and water are poor companions, vital bits eventually corrode and stop working.

More friendly are systems that detect water pressure change. With these, pump water pressure is normally maintained in the piping. When a tap is opened, pressure falls. This fall is detected by a pressure sensing switch that starts the pump.

The pump continues to run until the switch detects that the tap is closed and pressure is back up to normal. The switch then opens and the pump stops.

Pipe resistance

Like electricity, but far more so, water resists being moved through its conductor. A 12.5 mm water hose presents *five times* more resistance than does a 19 mm water hose, wasting energy accordingly.

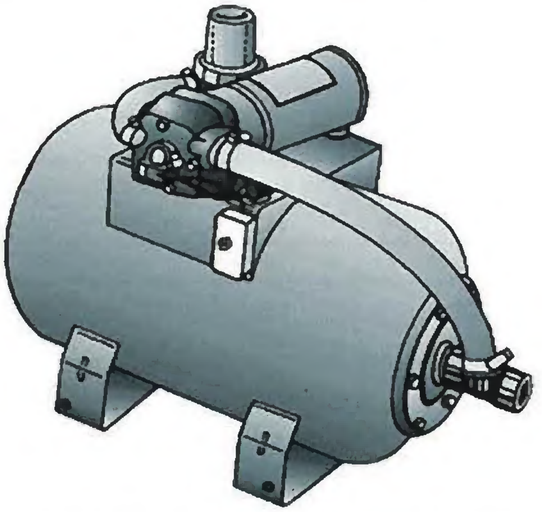
With the commonly used irrigation hose, the 32 mm size has only one third the resistance of 25 mm. The 40 mm size has only one ninth. This is a *major* issue for irrigation as increasing pipe diameter may save far more than it costs by enabling the use of a smaller pump, and less needed energy to drive it.

Every right angle bend adds 5% so more resistance. Where possible, use wide radius sweeping curves.

Pressure tanks

Basic pressure systems have the drawback that even tiny leaks or ambient temperature changes cause the pump to restore lost pressure - often in the small hours of the morning. Even vendor-styled 'quiet' pumps make quite a racket (but the Shurflo WhisperKing is quieter than most).

High-tech washing machines and dishwashers turn the water on and off scores of times each washing cycle. Each causes the pump to start and stop. As a pump's starting draw is at least twice its running current, energy consumption is thus increased.



This pressure tank has the pump mounted sideways on top.

Pump cycling can be substantially reduced by including a pressure tank that contains a strong balloon inflated to about 140 kPA (20 psi), i.e. just below the pressure switch's cut-in setting.

The pumped water progressively compresses the balloon until the pump's maximum working pressure is reached - about 315 kPa (45 psi). The pressure switch opens and the pump turns off.

The inflated balloon's pressure on the water provides ongoing system pressure until the pressure switch detects it is necessary to switch the pump back on. This is typically when half of the tank's volume is used.

A 20 litre tank thus provides about nine or ten litres of water between each pump cycle.

Given an adequate size tank, constant pump stopping and starting is considerably reduced. Water supply is silent between pumping cycles, water pressure is steadier, pumps last longer, people sleep more soundly. And the system uses a fraction of the previous electrical energy.

Constant pressure pumps

Another solution (for typical RV and marine use) is the Shurflo Revolution pump. When water is drawn it runs at full pressure but has an internal bypass within the pump from which water is drawn.

This pump consumes about some 50% more energy than most pumps of this capacity. It does not approach the pressure tank approach in efficiency but is compact and easy to install.

It is suited for larger motor homes, coaches and boats where the higher energy draw is more acceptable.

A second type (the Extreme series) has a microprocessor controlled system that senses the flow rate and varies the pump's speed accordingly.

Its energy draw is thus more or less proportional to the volume of water drawn.

The maximum pressure is 420 kPA (60 psi), similar to a typical town supply, and thus suitable for large RVs and coaches.

The Shurflo Extreme water pump. Pic: Shurflo.

Computers and TV

Current (late 2016) higher efficiency 36 inch (90 cm) LED TVs draw about 60 watts. Many of the 14 inch (36 cm) 12 volt TVs use far older technology. Some draw up to 80 watts.

All should be switched off at the power outlet as they continue to draw some energy if switched off only from the remote control. The same applies to masthead amplifiers, signal units used with satellite TV dishes and almost anything running from 230 volts. The loss is caused by filters that limit minor clicks on radios and TVs when appliances are switched on or off via a remote control. Turning the power off at the wall switch precludes that wastage.

Television

Well over half a TV set's energy is used by the screen and its drivers. It is proportional to the square of the screen's diagonal. LED screens usually draw the least.

Set top boxes enable analogue TVs to display digital programs. They may not work well or suffer damage unless run from mains power, or a sine-wave inverter. It is *far* better to buy a low energy digital TV.

Sony 36 cm LED TV. Pic: Sony.

Computers

Desk top computers draw up to 750 watts. This is too high for solar. The most practicable solution is one of the still available 18 inch lap top computers. Many double as a TV. They cost more than desk top units but prices continue to fall.

Most computers need to be switched off at the wall outlet after they are shut down as they otherwise continue to draw substantial power.

Bubble-jet printers draw only a watt or so whilst idling. Older laser printers draw up to fifteen watts. Both use far more whilst printing (laser printers draw up to 1000 watts). This is not a problem for the odd letter, but becomes one if needing to print downloaded reference material etc.

Low-voltage conversion

Some computers (and printers) run from 12 volts dc via a 230 volt ac adaptor. If you understand electronics, or know someone who does, you may be able to bypass the adaptor and run the equipment directly from 12 volts. This is more efficient than inverting to 230 volts and then using yet another black box to convert it down again to the 12 volts dc often required.

Alternatively, purpose-built dc-dc converters do the same job - but *only* that job. Their limited use is offset by their being just large enough for their purpose, so waste less energy.

Housing equipment

Neither computers nor TVs need sprung mounts, but are damaged by rattling around. Fix them rigidly, or pack them so they cannot move. The set-top boxes (used to enable pre-digital TVs to receive digital programs) are known to suffer damage unless securely located.

Be wary of wall-mounted TV brackets. Rough roads and corrugation can cause the bracket to vibrate and fracture, or the screws to pull out of the wall. Then down comes bracket, TV and all.

Both TVs and computers run just fine from sine-wave inverters, but some modified square-wave inverters cause problems. Few if any will run laser printers. Some are likely to damage them.

Communications

For those seeking to use only solar power in homes, energy can be saved by having a fixed land line service and a single *basic* telephone handset. Such handsets are powered via the local telephone exchange and thus save the minor but otherwise constant draw of the often used wireless speaker phones. The latter are handy but they draw energy constantly, including whilst on standby.

Mobile phone & wireless broadband

Telstra's NextG (3G, and 4G services) increasingly provide coverage across most of the more populated areas of Australia, and along many of its major highways. As of late 2016 only the populated areas of the Northern Territory and inland Western Australia are covered. Much of the inner land mass is still not.

The super-fast 4G (1Gbps) network will begin rolling out in late 2016 initially in central Sydney, Melbourne and Brisbane, with further expansion as Telstra builds out the network.

4G USB modem. Pic: Laurie Hoffman.

It will have maximum upload speeds of 150 Mbps on compatible devices, which will include a Netgear/Telstra 1Gbps hotspot device, coming also in 2016.

Read more: http://www.smh.com.au/technology/technology-news/mwc-2016-telstra-announces-1gbps-network-coming-in-2016-20160222-gn0s3y.html#ixzz487ibCSe6

Laptop computers and iPads/tablets connect to 3G and 4G either via a USB modem, a wifi modem or a built in SIM card. Smart phones can be used as 'wifi hotspots' to connect other devices to the internet such as lap-tops and iPads/tablets (using your included mobile phone data allowance or additional browsing pack data).

Some older modems require a 230 volt supply but can readily be run from solar via a sine-wave inverter. The draw is only 50 watts or so, but it's worth buying an inverter of at least 150 watts as it will prove useful for powering small mains electrical equipment, such as a small TV or laptop. Newer wifi modems have inbuilt batteries which need to be recharged using 230 volt or 12 volt chargers.

Mains-voltage phone chargers draw only a few watts but, unless used at the same time as other appliances, will keep an inverter drawing continuous power. This is a nuisance for people who charge mobile phones overnight.

Older mobiles recharge in an hour or two, while smart phones take a bit longer, but the inverter and power supply continue to use energy for the rest of the night.

Where feasible, try to recharge phones during the day.

A more efficient method, where voltage permits, is to charge the phone via a 12 volt adaptor using the RV's or the cabin's 12 volt supply. Some older mobile phones run on five or so volts, thus precluding such usage.


Smartphone installed in a motor home. Pic: Laurie Hoffman.

In-vehicle mobile phone kits have efficient inbuilt 12 volt chargers and also connect to an external antenna that considerably enhances signal strength and extends usable range.

Satellite phone

This is by far the most generally reliable form of outback communication, but requires an unobstructed line of sight between the satellite 'phone and the satellite. Australia's is low down and to the northwest: it is over Papua New Guinea.

Most hand-held mobile satellite phones have a short extending antenna, but some have provision for plugging in a high gain antenna for use in areas of marginal reception.

Satellite phones use more energy than do normal mobiles, but can be powered via plug in converters from 230 volt inverter power, or alternatively from 12 volts dc. They can be readily be run from solar.

Author's wife (Maarit) using her solar charged Iridium satellite 'phone - in Western Australia's mostly unpopulated Kimberley. Pic: Author 2007.

High Frequency radio

HF radio now has limited value for general communications as it provides coverage only between HF transceivers across limited and far from reliably predictable areas. In particular, there is a 'skip distance' of typically 70-100 km from the transceiver across which communication is only rarely possible.

The radios use 20-100 watts when transmitting, and a bit less when receiving. This is not serious for short calls, but becomes so if the set is left on 'stand-by'. An alternative is to switch the unit on only whilst driving, or at agreed times, allowing unscheduled incoming calls to be intercepted by private HF service message banks.

Whilst still in vogue, HF radio is now best left to enthusiasts for whom it is part communications but mostly hobby. It is also a heavy power user - although solar can cope.

CB radio

CB radio is still very much in use, and is now extended from the previous 40 channels to 80 channels. Its range depends on the nature of the terrain, from line of sight to 50 km or more.

Short range hand-held transceivers are also available. Caravanners in particular use them to advise their partners when reversing into tight places etc. This can be done by having a pair of transceivers, or having just one used in conjunction with the vehicle's own CB.

In-car CB radios are normally muted to remain silent between signals. It's easy to forget they are still on when you leave the vehicle, resulting in a flat starter battery (but readily recharged if you have solar modules). Avoid this by wiring the CB radio via the ignition switch.

Useful Telstra links:

http://telstra.com.au/mobile-phones/coverage-networks/our-coverage/coverage-search/

Telstra mobile broadband coverage map:

http://telstra.com.au/mobile/networks/coverage/broadband.html

Telstra Mobile Broadband devices (contract and pre-paid):

http://telstra.com.au/bigpond-internet/mobile-broadband/

http://telstra.com.au/mobile-phones/nextg-network/

Scaling the system

Previous sections provided an overview of what is and what is not economically feasible with solar. This section shows how to work out what size and how many solar modules and batteries you need for virtually any sized system, from a single light in the back of a VW Kombi, to systems for large cabins.

The starting point is to list what you believe you need, do some basic sums, and see how it works out. Examples on pages 52-58 describe actual proven systems. If your proposed energy usage is a lot higher than a system described there that seems close to your needs, you may need to reconsider your plans as your system will otherwise cost more than average.

Table 1 - Typical consumption - in watts

Cassette/CD player	**30**
Coffee grinder	**75**
Computer (laptop)	**20-30**
Computer printer	**70**
Fans (12/24 volt)	**10-25**
Fridges - see text on pages	**33-35**
Lights 12-volt LED	**2-5**
Lights 12-volt halogen (each)	**10-20**
Lights - 240-volt fluoro (each)	**8-18**
Macerator	**300-350**
Microwave oven ('800 watt') *	**1500**
Mobile phone charger	**5-10**
Radio	**15-20**
Sewing machine	**75-100**
Stereo	**50-60**
TV (10-14 inch)	**20-40**
TV (16-20 inch)	**50-80**
DVD	**30**
Washing machine (on cold water)	**200**
Water pump (12/24-volt)	**50**

Table 1 lists typical appliances that are practicable to run from solar in RVs and cabins. Use this list to make up your own version of Table 2 (page 45).

Enter the watts used by your own appliances (particularly of an electric fridge). If unknown, use the (typical) consumption listed.

If usage is shown in amps for 12 volt devices, multiplying by 12 converts it to watts.

For 24 volt systems multiply by 24.

Next, and using the data from your own Table, complete Table 2 - page 45.

* A microwave oven's wattage rating relates to its heating capacity, not the power consumed in generating that heat. A typical '800 watt' microwave oven draws about 1350 watts, or about 1500 watts if via an inverter, allowing for both the inverter and charging losses.

Table 2

1. In column A, list all lights and appliances.

2. In B, enter the wattage, or the total wattage if more than one device (such as lights) will be used at the same time. For anything driven via an inverter made since 2005, add 10%. If that inverter was made prior to 2005, add 15%. In practice it is usually more cost effective to update that inverter to a post 2014 unit. This applies also to appliances. Most quality appliances made from 2014 onward are more efficient.

3. In C, enter the hours each is used daily. Use likelihood, not rare maxima.

4. Multiply each entry in B by the respective entry in C.

5. Enter the amount totals in D.

6. Total all the entries in D and add 15% for charging/recharging losses.

The total shown in 'D' is the probably daily draw and is the *minimum* amount of energy that needs (on average) to be generated each day to counterbalance that used.

As emphasised on page 17, solar modules typically produce about 70% of the industry-claimed wattage output. If cost and space permits, however, (as it often does with cabins, large motor homes etc) it is *well* worth assuming only 50% to allow for freak weather conditions etc, and to speed battery recharging after heavy use.

Doing so is not always possible but where it is that extra capacity will provide a truly robust system.

Column A	**Column B**	**Column C**	**Column D**
Device/s	**Watts**	**Hours/day**	**Watt-hours/day**
Total of Column D			
As in item 2 (above) add whatever necessary for inverter losses			
Total - the most probable watt-hours/day energy draw			

Two approaches

As stressed throughout this book, there are two main and different approaches to using solar in RVs and cabins. The first is to use solar to generate as much energy as you use, plus a 15% margin to allow for losses, and for short periods of unusually low solar input. Unless otherwise stated, this is the minimum amount of solar capacity that will provide for most typical RV usage. Where space allows providing about 20%-25% more solar capacity is well worth the now relatively small extra cost. This is most easily calculated by assuming that solar modules produce about 50% of that claimed.

The second approach is to supplement solar input by alternator charging batteries whilst driving, or from a battery charger powered by a generator's 230 volt output, and grid power when available: (pages 28-29). The following text on this page and the solar tables on the pages 48/49 are pertinent to both.

How many modules?

The method and data for calculating the solar capacity recommended in this book assume (as does the solar industry) that the typical ambient temperature will be mainly 20^0-25^0 C. If it is higher, you will need about 5% more solar capacity per 1^0 C increase.

The Peak Sun Hour Maps on the next page show the most likely maxima and minima for Australia in mid-January and mid-July. In most places, the solar irradiation varies linearly for the months in-between. From these maps you can ascertain the average daily Peak Sun Hours (PSH) most likely experienced.

Most people who use an RV for holidays assume about 4 PSH. For those who intend to travel year around, 3 PSH should suffice for all but the lower parts of Australia's south during mid-winter. There, a generator is usually needed as that area has about 1.5 PSH in June and July.

If you assume higher Peak Sun Hours than above, particularly if you have a fridge-freezer, consider carrying a back-up generator, or a fuel cell (page 29). Or use a three-way fridge running on LP gas to slash electrical usage.

From the previous chapters you already know how many watts you are likely to use each day. Multiplying that by the relevant number of Peak Sun Hours per day gives the *minimum* watt/hours that you need on average to generate each day. In practice you need more.

The Table on page 48 shows the most probable average daily output of *horizontally-mounted* solar modules. That on page 49, and primarily applicable to cabins, shows the most probable average daily output of modules mounted at the *optimum fixed tilt angle*. The Table on page 76 shows how to estimate that angle. This angle is not critical, variations of up to 10% either way make little difference to daily input.

As will be seen there are only minor losses in having horizontal mounting (and some gain in most parts of Australia except in winter).

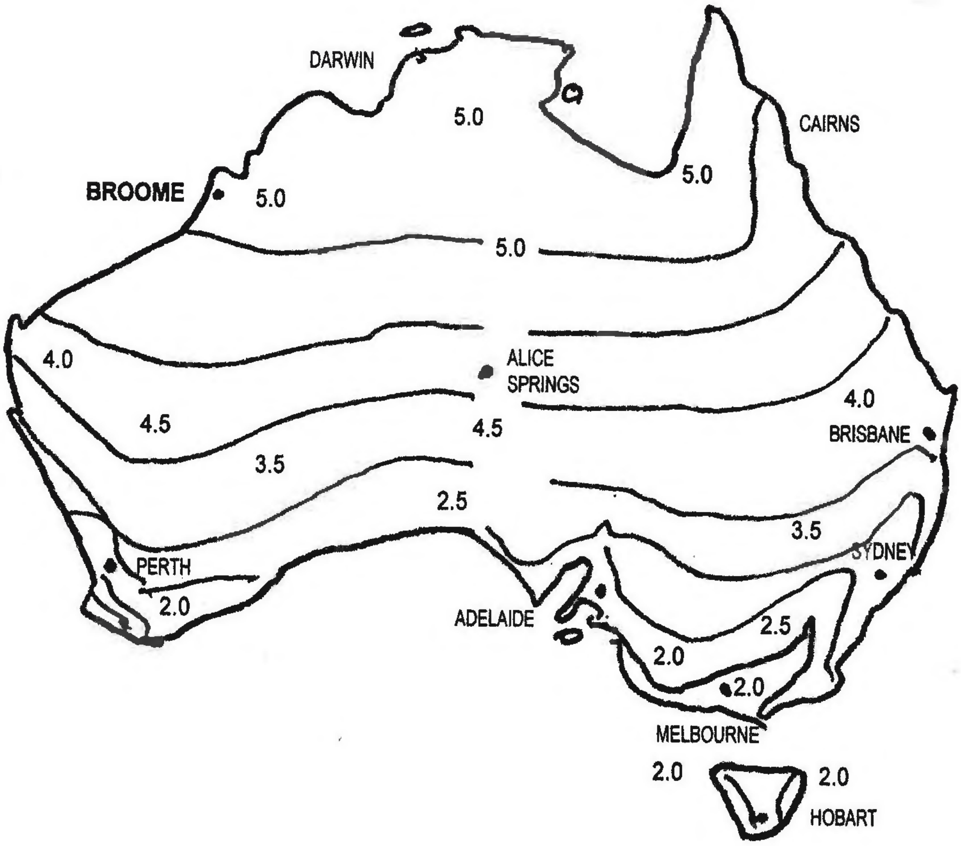
From there on it is simply a matter of selecting whatever combination of solar modules is required.

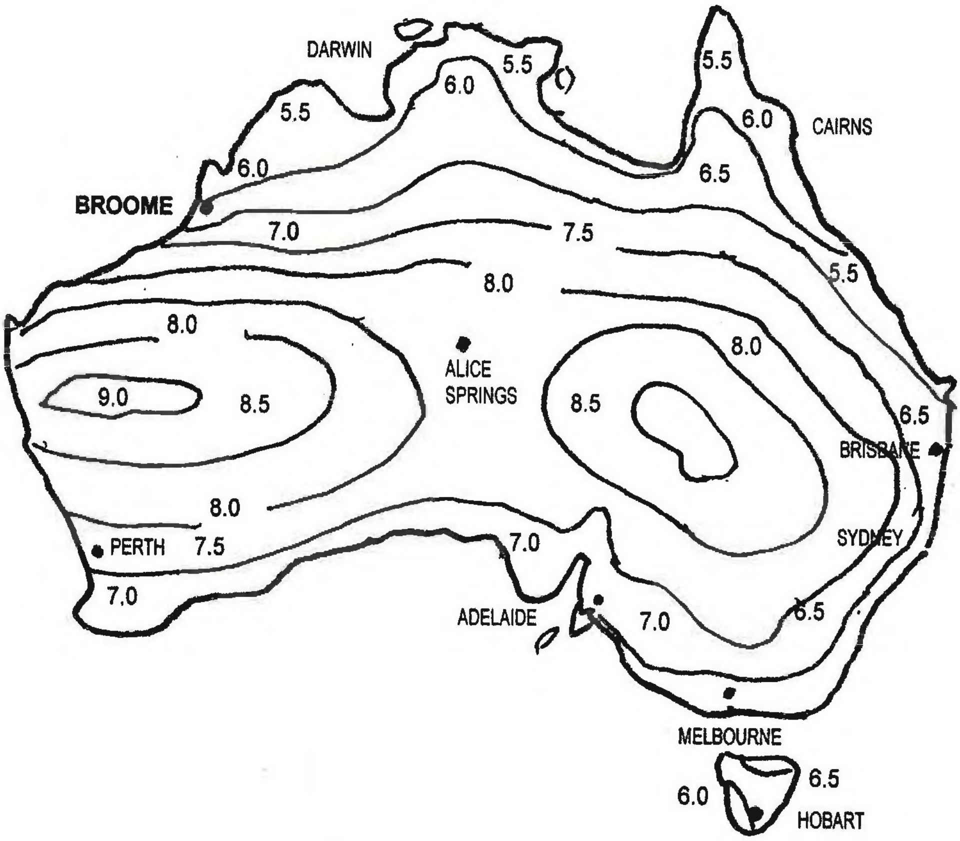
Mounting is eased by using identical sized modules, but it is fine to connect say, a 40 watt and a 100 watt module of similar voltage in parallel (plus to plus, minus to minus) to increase capacity - in this example, to 140 watts. It is also feasible to connect solar modules in series (consecutively plus to minus) to increase voltage, but all modules must be of identical wattage. Their voltage is additive. Err always on the side of too much solar capacity - *never* too little.

Supplementing the battery

With the exception of the big motor home in the example systems (pages 52-58), all the systems are substantially or wholly electrically self-sufficient. It is however readily possible to design the system such that solar energy only supplements that used. In other words, the battery still runs down, only later.

(Main text continues on page 50).





The upper Peak Sun Hour Map shows typical average irradiation for mid-July, the lower one for mid-January. Irradiation is more or less linear in between. To assess the probable daily input take the data shown for your area of interest and work on 70% of the nominal claimed output of most solar modules. (These maps, and the Tables on pages 48 and 49 are the sole copyright of Caravan & Motorhome Books - caravanandmotorhomebooks.com)

Solar output - modules flat

Modules: 64 watt	1	2	3	4	5	6	8	10
3 PSH	120	240	360	480	600	720	960	1200
4 PSH	160	320	480	640	800	960	1280	1600
5 PSH	200	400	600	800	960	120	1600	2000
6 PSH	240	400	720	960	1200	1440	1920	2400

Nominal 64 watt module

Modules: 80 watt	1	2	3	4	5	6	8	10
3 PSH	150	300	450	600	750	900	1200	1500
4 PSH	200	400	600	800	1000	1200	1600	2000
5 PSH	250	500	750	1000	1250	1500	2000	2500
6 PSH	300	600	900	1200	1500	1800	2080	3000

Nominal 80 watt module

Modules: 100 watt	1	2	3	4	5	6	8	10
3 PSH	187.5	375	560	750	935	1125	1500	1875
4 PSH	250	500	750	1000	1250	1500	2000	2500
5 PSH	310	620	935	1240	1550	1860	2480	3100
6 PSH	375	750	1125	1500	1875	2250	3000	3750

Nominal 100 watt module

Modules: 120 watt	1	2	3	4	5	6	8	10
3 PSH	225	450	675	900	1125	1350	1800	2250
4 PSH	300	600	900	1200	1500	1800	2400	3000
5 PSH	375	750	1125	1500	1875	2250	3000	3750
6 PSH	450	900	1350	1800	2250	2700	3600	4500

Nominal 120 watt module

Most probable output in watts of typical horizontally mounted solar modules.

Solar output - modules angled

Modules: 64 watt	1	2	3	4	5	6	8	10
3 PSH	135	270	405	540	675	810	1080	1350
4 PSH	180	360	540	720	900	1080	1440	1800
5 PSH	225	400	675	900	1225	1350	1800	2250
6 PSH	270	540	810	1080	1350	1620	2160	2700

Nominal 64 watt module

Modules: 80 watt	1	2	3	4	5	6	8	10
3 PSH	170	340	510	680	850	1020	1360	1700
4 PSH	225	450	675	900	1125	1350	1800	2250
5 PSH	280	560	840	1120	1400	1680	2240	2800
6 PSH	340	680	1020	1360	1700	2040	2720	3400

Nominal 80 watt module

Modules: 100 watt	1	2	3	4	5	6	8	10
3 PSH	210	420	630	840	1050	1260	1680	2100
4 PSH	280	560	840	1120	1400	1680	2240	2800
5 PSH	350	700	1050	1400	1750	2100	2800	3500
6 PSH	425	850	1275	1700	2125	2550	3400	4250

Nominal 100 watt module

Modules: 120 watt	1	2	3	4	5	6	8	10
3 PSH	255	510	765	1020	1275	1530	2040	2550
4 PSH	340	680	1020	1360	1700	2040	2720	3400
5 PSH	425	850	1275	1700	2125	2550	3400	4250
6 PSH	510	1020	1530	2040	2550	3060	4080	5100

Nominal 120 watt module

Most probable output in watts of solar modules facing north and tilted at latitude angle.

(Text continued from page 46)

Assume you have a 200 amp-hour battery that is *initially* charged to 90%, i.e. 180 amp-hours - or (as amp-hours times volts equals watt-hours) 2160 watt-hours. Discharging to 50% remaining, as battery makers recommend, leaves an available 90 amp-hours - that is about 1080 watt-hours.

If you use 500 watt-hours/day, you can thus stay on site for two days on battery power alone. If you wished to stay on site for six days (requiring 3000 watt-hours) - here's what you could do.

There is an initial 1080 watt-hours available from the battery: that is 180 watt-hours for each of six days - 320 watt-hours short of that which you need. Assuming 3 PSH/day and 70% efficiency that deficit can be supplied by two 80 watt solar modules.

Self-Sufficiency

Increasing solar capacity to two 120 or 130 watt solar modules will enable you to stay on site indefinitely, and with a well charged battery for back-up during overcast conditions.

In essence if you add enough solar to stay on site for six or so days, it needs only a bit more to be able to stay there (electrically) as long as there is sufficient sun. It is also practicable because solar capacity has become cheap.

Supplementing solar energy

Where you have occasional short term high electrical loads, 100% self-sufficiency becomes less practical. Here, it makes more sense to scale the system as above and use a quiet generator for those loads. Note however that National Parks and some caravan parks ban all generators.

Winter use

If you intend to spend time in southern areas such as Tasmania or around Melbourne during June-August (where there is usually less than 1.5 Peak Sun Hours) it makes little economic sense to scale the system for so little solar input. Recharge the battery bank via a small quiet generator driving a 230 volt charger and or via a fuel cell (if/when their costs afford). Or avoid such areas during mid-winter.

Electrical self-sufficiency

Electrical self-sufficiency *can* be achieved silently and pollution free and, if competently designed and installed, is ultra-reliable. It costs more initially, but batteries last much longer. Less frequent replacement goes part way toward the one-off cost of more solar capacity.

Many RV and cabin solar systems are close to self-sufficiency (or achieve that) much of the time, but if, on average, there is *any deficiency at all,* that system *must* eventually run out of power.

* Never cut back on solar capacity.
* Never have more battery capacity than you can fully charge by midday on almost all days of the year. If the energy is not captured it's not there to store.

The cartoon says it all.

Self-sufficiency as defined by Mr. McCawber (Charles Dickens): "Annual income twenty pounds, annual expenditure nineteen nineteen six, happiness happens. Annual income twenty pounds, annual expenditure twenty pounds ought and six, result misery." Solar is like that too!

Example systems

Two of the six following examples describe systems originally built by readers of pre-2010 versions of this book (when solar capacity was over three times today's price). One was later updated. Three are of systems designed in 2014 and 2015. One or another example is likely to be generally similar to what you have in mind. If it is, check your own calculations against the example as a guide to ensure that you are on the right track.

Example 6 is included to show what can go wrong in the event of a major misunderstanding between client and supplier (or of ignoring expert advice).

If you find that your estimated energy usage is much higher than the closest example shown, it may pay to revise your system as it is otherwise likely to cost more than average.

Watts the matter

As elsewhere in this book there is an unavoidable complication in that battery makers quote electrical energy in terms of volts and amps, but most solar and appliance makers use watts.

To convert volts and amps to watts, *multiply* amps by the system voltage (e.g. 12 or 24).

To convert watts to volts and amps, *divide* watts by the system voltage.

Refer also to page 17 re wattage claimed for solar modules - as the above will result in incorrect assumptions unless the curious solar industry practice (of overstating the most typical output) is understood. It is essential to work from the output the modules *actually* produce, rather than what *seems* to be claimed.

The examples here all use 12 volt solar modules of up to 120 watts each. Some of the owners used combinations of different sized modules that best fitted the space available. There is nothing rigid about this. To increase capacity you can parallel modules of the same voltage but of different wattage output.

To increase voltage (e.g. to 24 or 48 volts) modules can be connected in series but all must be of the same current output and of the same type). Unless otherwise stated, the example systems described were intended by their owners to be capable of running indefinitely whilst away from mains power.

Three-module tilting rack is an optional extra on the Trak-Shak brand of camper trailers. Pic: Brian Fox 2007.

Example 1. Small cabin

Column A Device	Column B Watts	Column C Hours/day	Column D Watt-hours/day
Fluro Light (2)	12	3	72
Radio	15	1	15
Portable TV (10 inch)	30	2	60
Water pump (12-volt)	48	0.15	8
Total of Column D			155
Plus 15% for system losses			23
TOTAL			**178**

This is a basic but adequate system built in 2002 for two people who spend most weekends from October through March in a small cabin a few kilometres north of Byron Bay (NSW).

The cabin has a three-way fridge that only runs on gas, a small 12 volt TV, a battery-operated radio that charges its NiCad cells from the 12 volt solar system, a couple of 12 watt compact fluorescent lights, and a Shurflo water pump. The average draw was 170 watt-hours/day (approximately 13 amp-hours/day).

At a realistic 4.0 Peak Sun Hours, the required total of 178 watt-hours/day (14.8 amp-hours/day) was comfortably supplied by a tilt-angle mounted 80 watt solar module producing about 225 watt-hours/day. Solar output was handled by a 10 amp regulator.

An 85 amp-hour gel cell deep-cycle battery provided three/four days usage with little solar input and up to seven days if TV watching was curtailed. The gel cell battery enabled the system to be left unattended during the winter months.

As long as that battery was left fully charged and isolated from the system, it still retained most of that charge at the end of winter. That original battery lasted for seven years and was replaced by a 100 amp-hour AGM in 2010.

It was still working well when last heard of in early 2015, but with solar capacity increased by 30% to assist during periods of little sun, and also extend battery life.

This example would suit virtually any usage where low price and simplicity is paramount. It is an ideal basic system for a basic camper trailer.

As with all the example systems described, savings can be made by using LED lighting, or having more and brighter lighting for the original consumption.

There is a lot to be said for basic systems like this. Ultra-simple, very reliable and with an electrical energy draw that is so low that battery capacity can cope with long periods of little sun.

Workings for above (as original)

Total daily energy demand (+10%) approx. 171 Wh/day =	14.25 Ah/day
Average solar input at 4 PSH (1 X 80 watt angled module) is approx. 225 Wh/day =	18.75 Ah/day
Battery 85 Ah (gel cell)	85 Ah

Example 2. Campervan (40-litre electric fridge)

Column A	Column B	Column C	Column D
Device	Watts	Hours/day	Watt-hours/day
Fluro Light (1)	12	3	36
Radio	15	1	15
Portable TV (10 inch)	30	2	60
Water pump (12 V)	48	0.25	12
Chest fridge (40-litre)	36	8	288
Total of Column D			411
Plus 15% for system losses			62
TOTAL			**473**

This example was built by a young couple for an extended low-budget trip around Australia in a converted 1974 VW Kombi. It is similar to Example 1 excepting that the three-way fridge is a 40 litre, 12 volt chest-opening Engel. Even though relatively small and electrically efficient, this fridge almost tripled current draw, necessitating correspondingly larger solar and battery capacity. There was also a second 12 watt fluorescent light that was used only occasionally.

The owners sought to use solar-only virtually everywhere at all times. The system was scaled accordingly. (Tasmania and the Eyre Peninsula were visited, but outside the three mid-winter months.)

At a realistically conservative 3.0 Peak Sun Hours, the owners chose to use three flat-mounted 100 watt modules. These generated a comfortable 630 watt-hours/day (70% of the claimed module rating). A 20 amp (PL 20) Plasmatronics regulator with monitoring facilities was included.

The 150 amp-hour battery capacity provides two/three days use with zero solar input (in practice solar input rarely drops below 25% of that normal for the area and time of year).

The owners reported that the system had never been anywhere near running out of power and that the original batteries appeared to still be in excellent condition.

Again, a preferred type of system: economic, simple and reliable. It provides what most people need for basic camping and cabin living comfort.

Workings for above (as at present)

Total daily energy demand is 473 Wh/day =	39.5 Ah/day
Average solar input (3 X 100 watt modules = 630 Wh/day)	52.5 Ah/day
Batteries (two by 75 Ah)	150 Ah

Example 3: Small motor home (60-litre electric fridge)

Column A	Column B	Column C	Column D
Device	Watts	Hours/day	Watt/hours/day
LEDs (3)	7	3	63
Radio	5	1	5
Appliances (via inverter)	350	0.5	175
LED TV (16 inch)	30	3	90
Chest fridge (120 litre)	60	10	600
Water pump (12V)	60	0.25	15
Total of Column D			948
Plus 15% for system losses			142
TOTAL			**1090**

This system was built by a couple who had previously travelled extensively in a small campervan but had now bought a 7 metre Toyota Coaster. They intended to winter only in warm sunny places and assumed a (rather optimistic) 4.5 Peak Sun Hours. As in example 2, they used a chest fridge but of 120 litres - using an extra 100 mm of insulation to limit daily draw to only 600 watt-hours.

The system retained the previous 350 watt inverter to run a blender, a small computer via a 230 volt adaptor, and a new (in 2015) 16 inch LED TV. There are five LEDs lights (all 7 watts). Not all are used at the same time (the draw has been calculated accordingly).

The required 1090 watt-hours/day energy is supplied by four flat-mounted 100 watt modules producing (a rather marginal) 1260 watt-hours/day. There is a 30 amp solar regulator with monitoring facilities.

A 250 amp-hour AGM battery bank (often discharged by 50%) provides a little over three days comfortable usage with next to no solar input.

This system has worked well so far but really needs 25%-30% more solar (for which there is ample roof space) to ease the load on the battery when solar input is low.

Workings for above

Total daily energy demand is 1090 Wh/day =	91 Ah/day
Average solar input 4.5 PSH (4 X 100 watt flat-mounted modules = 1260 Wh/day) =	105 Ah/day
Batteries (two by 125 Ah AGM)	250 Ah

Example 4. Average caravan/motor home

Column A	Column B	Column C	Column D
Device	Watts	Hours/day	Watt/hours/day
LEDs (5)	7	3	105
Radio	15	1	15
LED TV (16 inch)	30	3	90
Fridge (170 litre)	80	12	960
Water pump (12 V)	48	0.5	24
Total of Column D			1194
Plus 15% for system losses			185
TOTAL			**1380**

The most typical RV usage is occasional weekend and long weekend trips, plus an extended tour every year or so. Given minor variations, this system and its usage is typical of tens of thousands of such medium-sized caravans and motor homes. Such a system also suits many small/medium sized cabins.

As they never travel during the three mid-winter months, the owners of this particular (motor home) system originally settled for 4.5 Peak Sun Hours. Following the growing trend to bigger fridges, this example uses a 170 litre 12 volt compressor unit. The required energy of 1380 watt-hours/day was originally obtained from four by 130 watt modules (producing about 1640 watt-hours/day). A 40 amp MPPT solar regulator is used. Battery storage is three 120 amp-hour AGMs.

Although the owners originally decided against it, carrying a back-up generator is advisable for any solar-driven systems with a largish electric-only fridge. In this case it was truly pushing their luck as the solar capacity was not only marginal, but assuming 4.5 PSH is far too optimistic.

The owners found out the hard way (a fridge full of warm beer) that the solar capacity was indeed inadequate. My advice was that increasing solar capacity by 50% -60% would result in less chance of dead batteries and a warm fridge - and that it is still advisable to carry a 1000 watt quite inverter-generator plus a battery charger run from its 230 volt output. Or stay as is and use a three-way fridge running on LP gas whilst camping.

The owners added 50% more solar and also bought a 1 kW generator plus 230 volt battery charger and have had no further problems.

Where, as in this example, there is intermittent use, battery choice and care is a major consideration. The AGM batteries used here hold well over half their charge for a year or more if initially fully charged. Unlike conventional lead acid batteries, they suffer no damage if less than fully charged.

Workings for above

Total daily energy demand is 1380 Wh/day =	115 Ah/day
Average solar input 4.5 PSH (4 X 130 watt modules 1640 Wh/day) =	136 Ah/day
Batteries (3 X 120 Ah AGM)	360 Ah

Example 5: Large caravan

Column A	Column B	Column C	Column D
Device	Watts	Hours/day	Watt/hours/day
LEDs (5)	7	3	105
Radio	15	1	15
Portable TV (20 inch LCD)	40	2	80
Fridge (three-way)	N/A	N/A	N/A
Microwave oven	1300	0.1	130
Other appliances (via inverter)	350	0.5	175
Water pump (12 V)	60	0.5	30
Fan	20	3	60
Laptop computer	36	0.5	18
Total of Column D			613
Plus 15% for system losses			92
TOTAL			705

Caravanners have used three-way fridges running on gas for well over half a century, but those made prior to 1996-2000 lacked performance in any but mild climates. Further, many were (and sadly still are) badly installed. The more recent 'T-rated' units however work superbly - subject to competent installation (as is stressed throughout this book).

The caravan in this example has a 220 litre such unit and the owners say that it works really well even on days that are well over 40^0 C.

A major benefit of three-way fridges is that they work independently of solar input. If there is little sun, it is readily feasible to cut consumption by not using any major energy consumer, such as a microwave oven. It is thus feasible to design such systems without providing a large margin for extended cloud cover.

This unit is a six metre twin-axle caravan used for semi-permanent living and travelling, often staying on site away from mains power for several weeks at a time.

The owners spend most of their time north of the Brisbane/Geraldton line and opted for a realistic 4.0 Peak Sun Hours. The required 705 watt-hours/day was obtained from two flat-mounted 150 watt modules producing 840 watt-hours/day. A 20 amp regulator was adequate. The high draw of the microwave oven necessitated AGM batteries. The owners chose two by 100 amp-hour (but three would better cope with the high current drawn by that oven).

The typical energy draw is usually only 550 watt-hours as it is rare to use all five lights at the same time, and the microwave oven is used only occasionally.

This example highlights the *huge* electrical savings if using a three-way fridge. The owners say that the fridge, on average, uses 0.35 kilogram/day - a 9 kilogram bottle typically lasts about three weeks. They carry a spare anyway. LP gas is obtainable almost anywhere - but is costly in outback areas.

Workings for above

Total (max) daily energy demand (705 Wh/day) =	59 Ah/day
Average solar input 4 PSH (2 X 150 watt flat-mounted modules 840 Wh/day) =	70 Ah/day
Battery (two by 100 Ah AGM)	160 Ah

Example 6: Coach conversion (old 500 litre fridge)

Column A	Column B	Column C	Column D
Device	Watts	Hours/day	Watt/hours/day
Incandescent lights (6)	36	3.0	688
TV (42 inch)	170	3.0	510
Fridge (electric 500 litre)	300	14	4200
Microwave	1300	0.5	650
Washing machine	250	0.5	125
Water pump (12 V)	60	0.5	30
Fan	50	5.0	100
Total of Column D			6303
Plus 15% for system losses			945
TOTAL			**7250**

As with an example in a previous edition of this book, this system illustrates just *how* badly things can go wrong when an ambitious project is attempted by someone with no prior knowledge of solar and RV electrics. It was worsened by retaining a close to 25 year old large and energy gobbling fridge and incandescent lighting) in an otherwise well self-converted coach.

The owner/builder reasonably (but wrongly) assumed that solar modules produce that claimed. He also assumed they produce their claimed full output whenever/wherever the sun is shining (from dawn until dusk). He had no knowledge of the Peak Sun Hour concept and assumed the equivalent of 12 PSH.

On this basis he installed six 100 watt solar modules on the massively flawed basis they would produce about 7200 watt-hours/day. Reality however would be 1600 watt-hours (133 amp-hours) on rare good days but more typically 1200 or so watt-hours/day (100 amp-hours/day).

Worse, not initially realising the need for a solar regulator, the solar output was connected directly across the then unloaded 800 amp-hour bank of (fortunately second-hand) 12 volt lead-acid deep-cycle batteries. The batteries took a couple of weeks to fully charge - then progressively overcharged. They boiled themselves dry a few weeks later.

Fortunately the owner then realised he was way out of his depth. Following advice on a forum he bought a 2010 version of this book and also contacted me for advice (and agreed to provide the details of this example in exchange).

The problems were readily fixed. I advised taking the fridge to the tip and to install a new and efficient 220 litre compressor unit, fit LEDs into the existing light fittings - and to install four 100 amp-hour AGM batteries plus a solar regulator. Allowing for 15% losses the final energy draw was just over 2500 watt-hours/day (about 210 amp-hours/day). Or about 1850 watt-hours/day (155 amp-hours/day) if the microwave oven was not used.

The owner opted to retain the existing solar capacity and added a 230-volt, 3 kW Onan generator and 60 amp battery charger to keep the AGM batteries always above 50% charge.

This conversion had, to put it mildly, a bad start but ended up working reliably.

Workings for the original

Total daily energy demand 7250 Wh/day =	605 Ah/day
Average solar input 6.0 PSH (6 X 100 watt modules) 1600 Wh/day =	133 Ah/day
Batteries (eight 100 Ah - second-hand lead-acid)	800 Ah

Example 7. Big fifth-wheel caravan - (low energy)

Column A	Column B	Column C	Column D
Device	Watts	Hours/day	Watt/hours/day
Fluro Lights (4)	18	2	144
LED reading lights (3)	2	1	6.0
Radio	15	1	15
TV (LCD 26 inch)	100	2	200
DVD	20	1	20
Kitchen appliances	500	25	125
Laptop computer	36	1	36
Water pumps (two by 12 V)	48	0.5	24
Heater pump (winter only)	20	6	120
Total of Column D			690
Plus 15% for system losses			103
TOTAL			793

This, an interesting contrast to Example 6, is a very large (11 metre) fifth-wheel caravan used for permanent living. It has central-heating and a 26 inch LCD TV, yet uses less electrical energy than many a camper trailer! There is a big Dometic 'T-rated' three-way fridge in the trailer. A cab-located 12 volt fridge/freezer, runs from the alternator and solar to charge a 100 Ah AGM auxiliary battery. It is normally used only for shopping but can be used for back-up if required. (Its rare draw is not thus included.)

Whilst the 793 watt-hours/day (including 15% excess) could be very comfortably derived from four 120 watt modules, the owners opted for six. Three are on the towing vehicle's cab, the other three on the front roof of the trailer. At a combined 1350 watt-hours/day, available input is far higher than needed but enables each vehicle to be electrically independent. The battery bank can be similarly split.

Both systems are normally paralleled. In this mode the then combined 480 amp-hour battery bank provides 5-6 days use with virtually zero solar input. The trailer can be used independently at 4.0 PSH/day. Paralleled, the system runs happily at 2.0 PSH/day!

The inter-vehicle feed is via a 35 sq mm two-metre cable and Anderson plugs and sockets. A 30 metre 16 mm^2 cable interconnects the units when further apart. There are two separate solar regulators.

The towing vehicle is normally in the sun and the cable-connected fifth-wheel caravan in semi-shade. This provides adequate charging almost all the time. When used apart, the two sets of batteries charge unequally, but self-equalise over time once interconnected.

The heater pump in the equipment list is part of the rig's (diesel) central heating system. Whilst a generator is carried, it is used only for running big power tools.

This is an excellent and versatile (albeit costly) system. Some 160-180 watt/hours could be saved by replacing the fluro lights by LEDs; and by replacing the TV by an LED unit (of up to 36 inch).

If spending a lot of time in the tropics, it might be better to locate four modules on the towing vehicle and two on the trailer, enabling the trailer to spend more time in the shade.

(We used a generally similar but more modest concept for Nissan Patrol and TVan - page 93.)

Workings for above

Total daily energy demand (including 15% excess) is 875 Wh/day =	73 Ah/day
Average solar input 2.0 PSH (6 X 120 watt modules 1350 Wh/day) =	112 Ah/day
Batteries (two sets, each of two 120 Ah)	480 Ah

Extra-low voltage wiring

Extra-low voltage is the legal and technical term for clean direct current (dc) of less than 120 volts, and for alternating current (ac) of less than 50 volts. Confusingly, the term 'Low voltage' actually extends from Extra-low voltage to 1500 volts dc and 1000 volts ac. Page 66 also refers.

Given some dexterity with tools, installing Extra-low wiring and associated bits and pieces is not that hard to do. You may legally do all that work yourself, but Low voltage work must be done by a licensed electrician (see however page 89 re the curious RV manufacturing exception in Victoria).

Safety

A disconnected 12 volt solar module can produce up to 25 volts. This is enough to provide a considerable tingle, but the only likely danger is if the surprise throws you off the ladder. Twenty four volt modules generate up to 50 volts. This gives an even greater tingle but is unlikely to cause physiological harm. You need to be careful around 48 volt solar systems: their output can exceed 80 volts, and even more careful with the 72 volt systems used in some stand-alone systems: these reach a potentially lethal 110 volts.

When working with batteries wear fully-covering clothes and a face mask - or at least protective goggles. Even dilute acid can blind.

Always disconnect batteries before doing any work on or around an electrical system. Disconnect the *negative* (earth) lead first as accidentally touching earthed metal with the spanner then does no harm - but doing that whilst undoing the positive lead (with the earthed lead in place) can lead to that spanner literally vapourising. When reconnecting, and for the same reasons, attach the *positive* lead first.

The major risk with installed 12/24 volt wiring is excess current heating a cable sufficiently to melt its insulation and then setting fire to itself and nearby material. This is usually caused by a short circuit within an appliance, or by live cables touching. Guard against this by including a heavy fuse, or preferably a circuit breaker, as close to the battery as possible, and firmly securing all cabling against accidental movement. This is discussed in greater depth in the next chapter.

Absolutes

When wiring 12/24 volt electrical stuff there are a few absolutes. Most have to do with not losing energy through so-called 'voltage drop'. Akin to pressure forcing water through a pipe, voltage 'pushes' electrical energy through a cable. Even the best and thickest conductor (the copper part of a cable) resists this happening and, in resisting the flow, the cable's copper conductor heats up. Generating heat this way is useful if you are designing an electric kettle, but in wiring it is to be avoided.

Current is like the amount of water flowing in a pipe. The smaller and longer the cable and the greater the amount of current that it carries, the more it heats up and the greater the energy loss.

For appliances to work well, this loss should not exceed 1.5%-3.0% (that is 0.17-0.36 volts in 12 volt circuits) between the energy source and whatever is connected to it.

A 3% loss may not *seem* much: it is only 0.36 volt in 12 volts. The problem however is that lead acid batteries and appliances are only really effective from about 12.6 volts down to about 11.8 volts. If 0.36 volt is lost before it gets to the appliance, that's not a 3% loss of available voltage - it is close to 30%. This tends to be overlooked. Lithium-ion batteries however rarely fall below 12.9 volts in RV usage.

Fridges are particularly affected by voltage drop: with these, 0.3 volts is too high, 0.2 volt is acceptable, and 0.15 volt is a good target. In practice, one rarely sees a fridge that is connected by adequate sized cable. Most have over 0.5 volt drop and can never deliver their intended performance. Further, the 1.5-2.0 metre cables supplied with fridges may themselves have 0.2 or more volts drop.

Excess voltage drop usually occurs through not fully appreciating its effect on appliances, and/or misunderstanding auto cable ratings. It is also often due to following cable chart recommendations that are not applicable to RVs and is compounded by the lack of any RV industry wiring standard/s. The approach explained on page 63 circumvents both problems.

Voltage drop is proportional to cable length: the longer a cable, the thicker it must be. Heavy cable is not cheap. Where possible locate bits and pieces (consistent with ease of access) so as to keep the following cables short: solar modules to solar regulator, solar regulator to batteries, batteries to electric fridge, batteries to inverter and inverter to microwave oven. If it is not feasible to keep a cable short, all is still fine as long as adequately sized cable is used. It just costs more money.

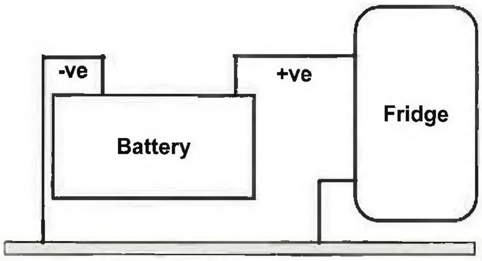
RV home wiring

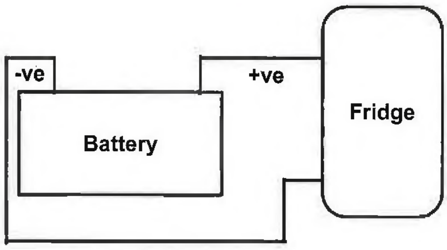
Electrical circuits that supply dc energy have two conductors: one positive, the other negative. Both are identical except for colour. Some motor homes (but rarely caravans) utilise the vehicle's chassis as the negative conductor. This saves cable, and because the chassis is so massive, voltage drop across it is reduced. In theory this seems good practice and is recommended by some major equipment suppliers. In *practice* however, it only works well when done to fully professional standards - but it rarely is. The sketches show both methods.

Unless the connections to the chassis are extremely well done (ideally by using welded-on studs that act as terminals), such connections invariably corrode and cause problems over time. The practice can also cause electrolysis corrosion through stray current travelling via the radiator etc.

Some recently made motor vehicles use the main earth strap from the chassis to the alternator and/or start motor battery as an essential voltage reference. If alternator charging is used all negative returns must be taken to the main chassis power post - not to the vehicle's battery.

Wire tables show recommended minimum sizes for lengths and current flow, but invariably for single conductors. This may confuse non-electricians, as, with twin conductor wiring, conductor length is twice the cable length. If the *distance* between the battery and whatever is connected to it is three metres, there will thus be a total of six metres of conductor.





Above: earth return.
Below: twin conductor (recommended).

Unless otherwise stated, this book assumes that twin conductor wiring is used. Presenting the information this way is also fail safe. The worst that may happen is that you'll use cable bigger than needed. But that's a 'good' and not too costly a mistake.

How cable is rated

The current a cable can carry depends on its conductor size. The International Standards Organisation (ISO) rates cable logically by quoting the cross sectional area of the conductor in square millimetres, usually abbreviated to mm², e.g ISO 35 is 35 mm².

Multi-strand ISO cable suitable for solar and other wiring is sold by electrical wholesalers and marine electrical suppliers, but only rarely by auto parts stores - see 'Auto cable' (below).

ISO (mm²)	0.75	1.0	1.5	2.5	4.0	6.0	10	16	25	35	50	70	95	120	150
Auto cable	2.5	3.0	4.0	5.0	6.0		8.0								5/0
AWG	18	17	15	14	12	10	8	6	4	2	1	2/0	3/0	4/0	5/0
B&S	18	17	15	14	12	10	8	6	3	2	0	2/0	3/0	4/0	5/0

Approximate relationship of the four most common cable 'standards'. Where discrepancies arise, most tables like this round down to the next thinnest size: but that increases voltage drop. This table thus rounds up to the next larger size. (Copyright: caravanandmotorhomebooks.com - but may be reproduced subject to full acknowledgment).

Cable made for fixed domestic and other wiring is ISO rated, but is best avoided for 12 volt RV wiring because it has only seven strands and lacks flexibility. It may fracture over time. That made for flexible power cords etc has many finer strands and is more suitable for RV use.

The cable most commonly sold in the USA (and some other areas) uses the American Wire Gauge (AWG) rating system. The *lower* the AWG number the thicker the conductor. The B&S (Brown & Sharpe) rating system is identical - except for minor differences in a couple of sizes.

Most conversion charts 'round-off' sizes to the next higher (i.e. thinner) even-number AWG/B&S equivalent, but this increases voltage drop. The Table on the previous page shows the *heavier* equivalent.

If money is not too tight, the very best choice is the so-called 'tinned copper' ISO-rated cable sold mainly by specialist marine electrical stores and also by Springer Low Voltage Electrics via its stores in southern Queensland.

Auto cable - a very real trap

Outside the USA, almost all *appliance manufacturers specify ISO-rated cable.* To them, a 4.0 mm cable implies a 4.0 mm^2 conductor. This introduces a trap for the electrically unwary.

Many countries, including Australia, use local and Asian made 'auto cable' for extra-low voltage wiring. (Auto cable is that stocked by auto parts and hardware stores.) For reasons that defy sanity, auto cable is rated and marketed by its overall diameter (i.e. including its insulation). But as insulation thickness varies hugely from brand to brand, and even types of the same brand, the resultant 'rating' shows only the size hole you can just poke the cable through.

Thus '3.0 mm' auto cable can (and usually does) have a conductor area of only 0.5 mm^2 to 1.5 mm^2. The commonly-used '4.0 mm' can be as small as 1.25 mm^2. That sold in Australia and New Zealand is more likely to be 1.8-2.0 mm^2 but rarely larger.

The '6.0 mm' auto cable has less variation. It is likely to be 4.4-4.8 mm^2. The 8.0 mm size (similar to AWG/B&S 8) varies from about 7.0 mm^2 to a little over 8.0 mm^2.

Auto cable is thus a real trap. It catches out any number of people including some installers. There is nothing wrong with it as such. It is readily available, and affordable. If specified correctly, it works just fine. But you *must* know its conductor area in mm^2. This is often printed in small type on the side of the cable drum. It is always revealed in the manufacturers' technical data and most stores have it. Insist on seeing that data. Making a mistake here can result in a system that barely works.

Current rating

A cable's 'current rating' can be even more misleading. It is simply a fire rating. It indicates *only* the current a cable can carry before its insulation begins to melt, and that varies from brand to brand. One imported '60 amp' cable has the same conductor size as a locally made cable sold as 25 amps.

Few vendors, let alone buyers, people understand this 'current rating.' Time and again one hears customers in auto parts stores asking for cable to carry (say) 30 amps but not specifying its length. They are sold '30 amp' cable regardless. Ignore this rating completely. Select cable *only as shown in this book* and you will automatically be well within its fire rating and achieve acceptable voltage drop.

A huge number of caravan and motor home electrical failings are directly due to excess voltage drop, and especially those relating to fridges. Cabins are more likely to be wired up by licensed general electricians - and not all know about this auto-cable rating anomaly. Most *auto* electricians are aware of this however, and not least because it is covered in *Caravan & Motorhome Electrics* as well as here - and both books double as auto-electrical text books. (The author also supplied the regular *Technical Notes* column in the auto electricians' trade publication, *AEAN*, from 2007 to 2015).

Here, shown approximately actual size, are 2.5, 4.0, 6.0, 10, 16 and 25 mm^2 conductors. This is a useful check of your existing cable sizes. The above shows the approximate area of the copper conductor - not the overall size of the cable.

Specifying cables

Most books and magazine articles in this area include complex tables that recommend cable size for various distances and current flow. All assume a specific voltage drop (typically 5% and *far* too high for RV solar installations) and are valid *only* for that. Further, most show only AWG/B&S sizes, with no guidance as to what to do if that cable is not available.

Since 2007, this and its associated books suggest a different approach to voltage drop calculation. This is officially legitimate following the release of an ISO (International Standards Organisation) adoption of a standard constant associated with voltage drop. See also page 65 re this.

Instead of confusing or misleading tables, they recommend actual targets for voltage drop that, together with the simple sum below, results in the approximate cable size (in square millimetres) for any desired combination of length, current and voltage drop. Picks the cable nearest to that size (but *never* smaller).

Where L is total conductor length (in metres)

I is total current (in amps)

Vd is desired voltage drop (in volts)

Then L X I X 0.0164 divided by Vd = conductor size (in mm^2)

Example 1: a 12 volt 1500 watt inverter drawing 130 amps, connected by twin cable to a battery one and a half metres away (i.e. three metres of conductor). We wish to keep voltage drop to 0.2 volt.

Applying the formula we thus have 3.0 X 130 X .0164 - divided by 0.2.

The result is 6.64 divided by 0.2 = 32.2 mm^2.

The comparison table (previous page) shows the closest size to be 35 mm^2 (also 2 AWG and 2 B&S).

The sum works equally well for (say) 24 volts.

Example 2: a 1500 watt (but 24 volt) inverter draws 65 amps and is connected by twin cable at one and a half metres distance from the battery. The same percentage* drop at 24 V is 0.4 volt (not 0.2 volt).

The sum is thus 3.0 X 65 X 0.0164 - divided by 0.4.

The result is 3.2/0.4 = 8.28 mm^2. That's an easy one too. It is about 8 mm auto cable, 8 AWG and 8 B&S. The closest ISO size is 10 mm^2 and far from overkill.

(* That the required cable is only one quarter the size [not half] often surprises. The explanation is that for the same watts, the current draw at 24 volts is halved and, as it is primarily the *percentage* volts drop that matters, at 24 volts that's 0.4 volt - not 0.2 volt.)

12/24 volts - the choice

The above shows the advantage of using 24 volts, but decreasingly little 24 volt equipment is available for RVs excepting lights, water pumps, chargers and inverters. For a vehicle with a 24 volt alternator, consider retaining the 24 volt starter battery, then add a 24/12 volt dc-dc charger and 12 volt battery bank. Or stay with 24 volts, and run as much as possible from 230 volts via a 24-230 volt inverter.

Fixing inadequate wiring

If existing cabling is too light in a charging or a fridge circuit, replace the cable, or run a parallel cable to share the load.

In lighting circuits, replacing inefficient lights by items that draw less current will reduce or eliminate this problem. Replacing 20 watt incandescent globes by 10 watt halogen globes in the 1990s resulted in similar light levels for half the current - and hence half the voltage drop. The now universally accepted white and warm white LED lights draw so little current for more than adequate light that 1.5 mm^2 cable can be virtually relied upon to cope. Anything smaller is best avoided, but for reasons relating to mechanical strength rather than current carrying capacity.

Which cable is which - colour coding

Any colours tend to be used for extra-low voltage wiring but it is common to use red for positive, and black (or in some countries yellow) for negative. But don't rely on this. Jayco for example, uses black for positive and white for negative. Engel and many others use black with a white stripe for positive and plain black for negative.

Solar modules, batteries, appliances, wiring diagrams etc, indicate positive by a plus (+) and negative by a minus (-). They may alternatively be marked +ve and -ve respectively. Earth connections are marked either 'earth', or in the USA, 'ground'. Positive leads connect to positive (+) terminals, negative leads to negative (-) terminals.

Some electrical wholesalers supply numbered or lettered tags for cable identification. This is worthwhile for subsequent fault finding etc.

Making connections

Cables connect to electrical devices via plugs and sockets, crimp lugs, or are secured by set screws. Crimp lugs work by squashing wires tightly inside strong metal sleeves. Crimping works well as long as you use high quality lugs, but cheap ones tend to corrode and/or work loose after some years.

These lugs are colour coded. Red is used for 1.5 mm^2 cable, blue for 1.8-2.5 mm^2, yellow for 4-6 mm^2. It is essential to use the right size lugs and a good purpose-made crimping tool.

If used correctly these tools create a cold weld. Pliers only *appear* to work. They cannot form that desirable 'cold weld'. Connectors crimped that way may seem to be just fine, but typically fail after a year or two.

Crimp lugs suffer from a wider range of quality than is normal with electrical products. The cheapest are made from folded up sheet metal (you can see the join if you look inside them).

It is worth buying aircraft quality lugs - these are formed from extruded tubing. They cost a lot more but their use will assist to avoid subsequent problems.

Soldering crimp lugs is absolutely not advisable, especially for wiring that is subject to vibration: it locally stiffens the copper conductor which may cause it to fracture over time. It may also cause the copper to corrode.

Crimp lugs vary in quality - from dreadful to aircraft certification. The best have seamless construction, not folded. They stocked by electrical wholesalers (they will supply retail if you pay cash).

Connections to solar modules are made by crimp lugs, or by forming the copper into a loop held by a screw and shaped washer supplied with the module. Battery and inverter cables need crimping hydraulically. Manual crimping tools are far too small. Have these done by an auto electrician.

Form crimps only by using a high quality tool. You cannot do this properly with pliers. Pic: Digi-Key.

Support cables against movement by using plastic ties at not more than 400 mm spacing Those from electrical wholesalers are usually much stronger than those from hardware stores.

Protect cables also against abrasion, but don't run them inside closed tubing - that presents major access problems later. Instead, wrap cable/s in plastic spiral binding. An exception is where cable must run where later access is not feasible. There, use rigid or flexible electrical conduit.

Protect and strengthen the crimped connections by using (heat) shrink-wrapped tubing - both from electrical wholesalers.

If you do use conduit, having it slightly oversize assists pulling cables through it. Use a vacuum cleaner to suck through a cord - then use that cord to pull through the cable. If the cable sticks, a squirt of WD 40 or french chalk works wonders. Neither damages the cable.

Joining cables

Multiple cables may be joined or terminated via connector strips. They are made in sizes to accommodate three to twenty or more cables. Some accept different sizes (up to 100 mm^2 or so).

This waterproof connector accepts six cables.

They are also made as small lidded boxes in a choice of red, black or clear to indicate polarity and earth.

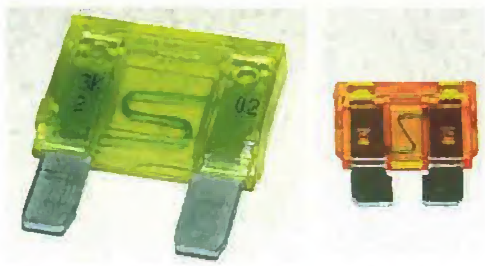
Heavy cables are best joined via terminal posts rather than the unsightly and dangerous cluster of leads often seen hanging off battery terminals.

The latter is particularly poor practice with vented lead-acid batteries as cable connectors and cable become corroded by acid fumes.

Fuses

One of the more serious electrical faults involves live conductors accidentally touching. Such heavy current may then flow that the cable melts and ignites nearby flammable material.

Circuit breakers or fusible links protect against this. They are inserted in the *battery end* of cables to protect the cable. Fuses are also used to protect appliances against fire or damage if a fault causes them to draw excess current.



Blade fuses (shown approximately full size). Use the larger size, for 20 amps and over.

These fuses need to be located close to the appliance. If you add a fuse, do it properly. Many electrical faults, particularly with big fridges, are caused by the fuse holders themselves burning out.

Typical 100 amp fusible link.

Avoid tubular glass fuses and their holders: they are seriously unreliable. Use the blade type instead. These fuses are made in different physical sizes. Use maxi size fuses and holders for 20 amps and over. Smaller sizes are known to overheat and even melt.

Above 30 amps it is better to use so-called fusible links. Fusible links are to some extent high current fuses made to higher standards.

Fusible links are like oversized fuses but have screw or similar positively locking connectors. Locate them where they cannot splatter anything valuable with moulten lead - these things go off like $100 fireworks.

Circuit breakers

There have been major developments in fuse technology, but following a major research study, insurers found a statistically significantly lower incidence of electrical fires where circuit breakers and fuses are located as above.

As a result, the use of circuit breakers (rather than fuses) to protect cables is strongly recommended in electrical codes. It makes sense to follow this recommendation.

Circuit breakers double as main circuit switches. They are invaluable for cutting power manually if a fault develops that does not trip the circuit breaker (such as a partial short circuit in inaccessible wiring). Such ability is much faster and safer than trying to remove a just blown fusible link.

In making this decision bear in mind that high quality circuit breakers are not cheap. Those that are tend to be unreliable and temperature dependent.

Unless you are prepared to pay for high quality circuit breakers, settle for 'fusible links' (from auto electrical stores). Safety-wise, they are a better proposition than cheap circuit breakers.

Master switches

Unless protected also by a circuit breaker or fuse, never install a master switch in any high current circuit (particularly dc).

If there is a short in that cable, opening an unprotected switch whilst it is carrying excessively high dc current will cause the opening contacts to form an arc. This ionises the air - enabling the arc to extend and be maintained. Where currents are high enough this arc can almost instantly vapourise a switch.

This effect does not happen with ac because both voltage and current pass through a zero state at 100 times a second - at 50 Hz. This extinguishes any arc.

Clipsal advises that its 230 volt ac circuit breakers can be used for dc applications below 48 volts but warns that they take longer to trip.

If attempting to do this contact Clipsal for advice. It seems pointless however as the company produces 12/24 volt dc versions at not that much higher price.

Dc circuit breaker.

Switches

Domestic 230 volt switches are not intended for direct current (dc) operation, but they work reliably enough if used at no more than 20% of their (typically 10 amp) rating.

Amps times volts equals watts so a 20 watt, 12 volt halogen globe draws 1.66 amps. This current is readily handled by a 10 amp 230 volt ac switch.

Two 10 watt, 12 volt globes equally draw 1.66 amps and are thus also switchable this way.

Alternatively, small ac/dc rated toggle switches are available from component suppliers such as Altronic and Jaycar Electronics. Most of these too are rated at about 10 amps ac, and 2 amps dc.

Twelve volt plugs and sockets

Early editions of this book (and my companion books in this field) advised users not to consider cigarette lighter plugs and sockets for anything drawing more than an amp or two - and preferably not at all. This was because, until recently, most lacked mechanical locking. When they inevitably worked loose they arced internally, becoming an only too-real fire hazard.


Hella 16 amp plug. Pic: Hella.

Whilst this advice generally still stands, Hella's up-market eight and sixteen amp version of these plugs and sockets include effective mechanical locking. Engel too provides good ones - with some having an internally fused plug.

The (UK) Bulgin company make excellent marine-rated 12 volt plugs and sockets (available from Electric Boat Parts in Sydney). Another alternative are the very much larger two-pin plugs and sockets available from Camec, Clipsal and others.

Avoid eBay specials. The fire risk is known and is too high to attempt to economise.

ISO Standard (page 62)

Re voltage drop. The previously used constant (of 0.017) was adjusted to 0.0164 a few years ago to bring it into exact line with International Standards Organisation standards.

Low Voltage wiring

To many non-electricians surprise, Low Voltage is defined (in Australia and New Zealand) as that exceeding 50 volts ac and not exceeding 1000 volts ac. Our so-called mains voltage used to be defined as 240 volts but to accord with EU standards (and enable local manufacturers to sell product overseas) was, in 2000, legally defined as 230 volts +10%/-6%. In practice much of it is still about 240 volts.

The 12/24 volts associated with cars and RV batteries etc. is legally known as Extra-low voltage. It is defined as being below 50 volts ac, and 120 volts (ripple-free) dc.

These terms thus have precise legal and technical definitions.

Caravans, campervans, motor homes and some cabins are exposed to potentially dangerous conditions that are less likely in fixed installations. The main risks are increasingly recognised and many requirements have changed in recent years. Some such requirements, such as that for double pole switching in RVs, are substantially different from domestic practice.

The installation of Low Voltage (i.e. mains voltage) wiring and associated work may only be done legally by a licensed electrical contractor. He or she is also responsible for certifying that the work has been done correctly. This restriction applies if the installed wiring is supplied only by an inverter or generator (if they are connected to fixed wiring) i.e, even if there is no external mains connection.

Experience shows that some electricians seem unaware that RVs electrical systems are *substantially* different from domestic practice, or do not always following the legally laid down requirements.

Retired electricians reading this are respectfully reminded that much of the Wiring Rule requirements they knew so well were substantially changed in 2001 and 2002, again in and 2007 and 2008. They were then substantially Amended in 2012. This is particularly true of the AS/NZS 3001:2008 legislation affecting RVs. It is advisable for those seeking electrical work to be done on an RV to ask a few discrete questions to ensure the electrician really *is* aware of the current requirements - and follows them.

Relocatable premises

In both Australia and New Zealand, relocatable premises must meet the requirements of AS/NZS 3000:2007, plus the requirements of AS/NZS 3001:2008 (both as Amended in 2012). These premises include registrable vehicles offering accommodation, e.g. caravans, camper vans, motor homes, camper trailers, and livestock and other transporters that have accommodation included. (In New Zealand this is extended to include many other categories including vending vans, mobile classrooms etc.)

Also included are non-registerable premises such as re-locatable homes, transportable huts (that includes cabins), and rigid and non-rigid annexes to the above. There are several further categories (such as canteens, mobile toilet blocks etc.) but these are outside the scope of this book.

Permanent connection exceptions

The provisions of AS/NZS 3000:2007 (as Amended in 2012) apply to re-locatable premises where an electricity supply has been permanently connected and where such premises are not intended to be relocated, e.g. coaches or caravans that have been rendered immobile, and cabins that are permanent structures. For these, the requirements of AS/NZS 3001:2008 (as Amended in 2012) do not apply.

Vital exceptions

As well as many minor differences, there are a few major and vital differences between electrical installations supplied by a connecting cable from an external socket outlet (e.g. in a caravan park or home), and those that are permanently connected to an electricity supply (as in a house or business).

One particularly relates to earthing. In Australia and in New Zealand, as well as some other countries, the neutral line is connected to earth in various specified locations. With this MEN (Multiple Earth Neutral) wiring, houses and business premises have the earth-neutral link made *within* those premises.

In re-locatable premises, such as caravans and motor homes that are supplied by a connecting cable from an external socket outlet, that earth and neutral link must be made *only* at the supply side of the connecting cable and site outlet: i.e. *not within the re-locatable premises.*

Whilst much of the above Standards are common to Australia and New Zealand, there are some differences between their respective requirements. These include an Australian (only) requirement for circuit-breakers and switches to be double pole (i.e. to switch both active *and* neutral leads). Further, and unlike general practice, an earth-neutral (MEN) connection must *not* be made within the RV.

In New Zealand, however, whilst the location of the earth-neutral (MEN) connection is now mostly as above, many older NZ caravans and motor homes still have earth and neutral linked *within* the vehicle. That earth/neutral link must be retained if no RCD has been installed.

Some NZ RVs have permanently connected supply cords that have an inbuilt RCD. With these too the earth/neutral link must *not* be made within that RV.

Power into the vehicle (socket outlets)

Caravan parks are legally required to have:

• Socket-outlets complying with AS/NZS 3112 (3 flat pins) and rated at not less than 15 amps.

• Or, (in Australia) socket-outlets complying with AS/NZS 3123 (3 round pins) and rated at not less than 20 amps.

• Or, (in New Zealand) socket-outlets complying with IEC 60309-2 (round pin) and rated at not less than 16 amps or 32 amps.

Each socket-outlet has to be protected by a circuit breaker and an RCD (residual current device).

Supply cables

From 2008 onward a change in the Standard ensured a maximum 5% uniform impedance (i.e. resistance to ac). This limit enables circuit breakers to open in time to save human life.

Cable rating	Conductor area	Length
10 amp	1.0 mm^2	25 m
10 amp	2.5 mm^2	60 m
10 amp	4.0 mm^2	100 m
15/16 amp	1.5 mm^2	25 m
15/16 amp	2.5 mm^2	40 m
15/16 amp	4.0 mm^2	65 m

Connecting cable lengths and minimum conductor sizes generally applicable to RVs). (This is Table 5.1 of AS/NZS 3001:2008 (as Amended in 2012. It supersedes that in previous editions of this book. Extract reproduced by courtesy of Standards Australia).

This enables a wider choice of supply cable lengths and conductor sizes, but is prejudiced if cables are joined end to end. The Standard thus now calls for supply cables to be of one single unbroken length.

It is advisable to use heavier cable than that specified if here is any risk of it being damaged.

10-15 amp adaptors

The use of 10-15 amp adaptor leads, or filing down 15 amp plug earth pins, has always been potentially dangerous. Doing so is now also illegal. This however causes problems where there are only 10 amp outlets.

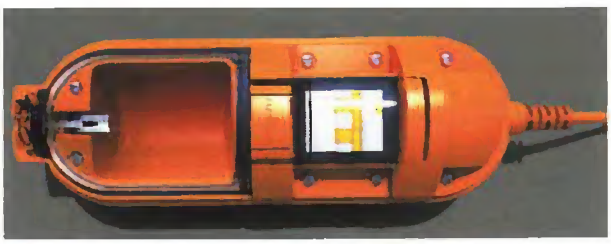
The *only* practicable and legally acceptable solutions are:

* Have a licensed electrician install a 15 amp circuit and socket outlet, or,

* Have the RV plug inlet and circuit breaker changed to 10 amp and use a 10 amp cable.

* Use a specially made cable that incorporates a 10 amp circuit breaker. These are available under the trade name Ampfibian.

A socket inlet that complies with the choice of restricting supply to 10 amps is available, but costly. You may also omit the socket inlet at the RV end and have the supply cable permanently attached. Some restrictions apply regarding a waterproof enclosure and mechanical fastening for the stored cable.



Amp-fibian 15 amp to 10 amp adaptor. Pic: Amp-fibian.

Vehicle inlet socket
The RV standard 15 amp socket inlet must comply with AS/NZS 3109.1, AS/NZS 3123 or (for NZ), IEC 60309-2. It must be mounted so that the earth pin is not uppermost and, if on the same side as an entry door, not less than 1.5 metres from any entry door, and not less than 150 mm from any opening.

Polarity
A possible hazard for RVs etc is that the power supply may be incorrectly polarised (i.e. active and neutral reversed). With correct polarity, a switch that breaks the active lead only, ensures a connected appliance is electrically dead. But, if the polarity is reversed, a switch breaks the neutral line only. The still live active line remains connected to a light or appliance presumed as 'turned off'. This can be fatal if someone, assuming power is off, attempts to replace a light globe, accidentally breaks the glass and contacts the live bits now exposed.

Reversed polarity is mostly caused by people (illegally) making up their own supply cables and reversing active and neutral at one or other end of the cable. It can also occur through incorrectly wired inlet and outlet sockets etc. To safeguard against this situation all new Australian RVs and re-locatable premises are required to be protected by double pole switches: i.e. that cut both active *and* neutral lines.

These requirements protect only new and upgraded vehicles. Incorrect polarity is still an ongoing problem. Many RVs made prior to 2000 or so may still have only single pole switches. So do any number installed subsequently by people (including manufacturers) unaware of the requirements.

For correct polarity, the active (brown or red) and neutral (blue or black) conductors *must* be connected to the corresponding terminals of plugs and sockets. Red or brown connects to the active (A) terminal, black or blue to the neutral (N) terminal, and green or green/yellow to the earth terminal.

Because New Zealand has tighter control over the supply outlet and cable polarity, plus obligatory inspections: single-pole contact breakers and switches are there deemed acceptable.

Polarity testing

Polarity testers are not expensive typically have three lights: red, green, and amber, that light up in various combinations to indicatecorrect or incorrect polarity and the presence or otherwise of an earth connection.

Incorrect polarity is readily uncovered by using an ac polarity tester. These cost about $15 and are stocked by hardware and electrical suppliers. Ac polarity testers also indicate whether a supply cable or caravan park power outlet is wired safely. They show what's wrong, including, for example, a lack of an earth connection. It is worth having one permanently in a socket outlet inside the vehicle.

An ac polarity tester warns of faults, but not of their exact location. A fault could be in the outlet checked, the cable leading to that outlet, or further back in the wiring. To find out, start at the furthest point (e.g. caravan park socket outlet), and work forward checking each stage.

It is not unknown for a caravan park to have one or more incorrectly polarised socket outlets. Not good, but less of a risk providing your RV has the legally obligatory (in Australia) double pole switching.

Inverters
Some cheap imported inverters have a floating neutral - i.e. the output is 120-0-120 volts. They may also have one side of their output connected to one side of the battery input, introducing a severe safety risk.

All such inverters are intended to be free-standing. They have power outlets into which appliances may be plugged directly. These inverters *absolutely must not be connected to fixed mains voltage wiring - even if mains electricity is never used.* If in doubt about compliance show this page to a licensed electrician and seek his or her advice.

Generally speaking (as there may be exceptions) if an inverter has inbuilt outlet sockets it is not designed or intended to be connected to main wiring. The result may be dangerous if attempted.

Change-over switches

A requirement, where a generator or inverter is connected to low voltage wiring, is for a 'break before make' double-pole change-over switch. This switch ensures that generator or inverter output cannot be accidentally fed into the grid network. It is intended to protect electricity workers working on the network (with power cut off from the main grid) and thus assumed safe for handling.

Cabling

Low voltage lighting cabling is usually 1.5 mm^2 (but see below). Power cabling is usually 2.5 mm^2. If Low voltage wiring is covered by thermal insulation, 2.5 mm^2 cable must be used also for lighting. The so-called 'building cable' (which has fewer strands of larger size) is liable to mechanical failure under vibration. It is fine for permanently installation in cabins, but not in RVs.

Separation of Low & Extra-low voltage wiring

Low voltage and Extra-low voltage wiring must be physically separated, or the Extra-low voltage circuit must use Low-voltage insulated cable. The bulk of such cable may however make the latter impracticable. It is simpler, and safer to install Low voltage and Extra-low voltage cables well apart. This cable separation is also required for wiring specific to a vehicle's on-road requirements.

Cable protection

Low voltage cabling must be run within rigid or flexible conduit everywhere it could be disturbed, including by vibration, road shocks and accidentally. Elsewhere it may be run along battens etc, but must be adequately supported at not greater than 400 mm spacing - as set out in AS/NZS 3000:2007 as Amended 2012. It must be protected by rubber or plastic insulating grommets where it passes through metal. Where cabling passes through timber it is good practice to smooth off the edges to the holes.

Kitchens & bathrooms etc.

There are any number of regulations governing the location of light fittings and socket outlets in or near kitchens, bathrooms, showers, and water. These regulations are laid down in the Standards and are well known and understood by most electricians, but sometimes (illegally) ignored by RV builders.

Certification

The previous need for independent inspection changed around 2002. Now, the licensed contractor takes responsibility for the system and issues a certificate accordingly.

Updating installations

As will be apparent, post-2000 electrical requirements are now different, more complex, and also more effective. They were revised following analysis of electrocutions that could have been avoided had RCDs been installed and made obligatory for all new work. Since 2002 the death rate in Australia from electrocution (mostly from supply cable faults) has fallen: from a hundred or so to under fifty a year.

Despite the increased safety, far from all pre-2002 RVs comply with the new system. There is no legal requirement to update but it makes every sense to have that done by a licensed electrician experienced in both RV work and the new requirements.

Exceeding requirements

Electricity regulations specify only *minimum* requirements. Electrical installation is a highly competitive business so these minimum requirements are what will be met unless otherwise requested.

There is a good case for *exceeding* these requirements. For example it is legal to run power and lighting from the same circuit, but it is better practice have them separated, each protected by an individual CB/RCD.

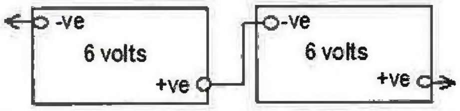
Installing batteries

Large capacity batteries are heavy and awkward. Two or more smaller ones are easier to handle than one big one. For 12 volt systems, you can have 12 volt batteries in parallel, or you can have one or more pairs of two 6 volt batteries connected in series.

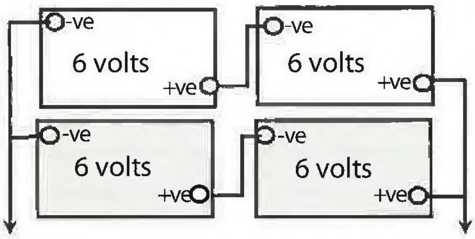
Don't buy into arguments for or against series or parallel connections: the pros and cons largely cancel out. Either way works fine subject to the following.

Parallel connection

Paralleled batteries *must* be of the same nominal voltage, and of generally similar condition. Contrary to campfire mythology however, it is fine to parallel batteries of even widely different amp-hour capacities. Each absorbs the charge current it needs and each delivers its proportional share of load current.



Twelve volts can be obtained by connecting to six-volt batteries in series.



To obtain higher capacity (at 12 volts) connect additional pairs of batteries in parallel.

Any combination of the same batteries always provides the same amount of energy - there is no way you can get more energy from batteries than that energy already in them.

Battery companies generally advise limiting the number of parallel connected batteries, or strings of series/parallel batteries. Most suggesting limiting it to four batteries or four series-connected strings of batteries, but the giant Exide corporation suggests that ten is still fine given the safeguards outlined above.

Battery makers originally advised against parallel connecting conventional lead-acid batteries *directly* with gel cell or AGM batteries. They advised against charging a conventional lead starter battery and gel cell or AGM auxiliary batteries from the same source. This is because both of the latter have far greater charge acceptance, and would thus rob the starter battery.

This issue was resolved in the late 1990s, by including a voltage sensing relay. This relay automatically ensures the conventional battery is adequately charged before further batteries are paralleled for charging. The relay also disconnects the protected battery if the voltage across it falls too low. Details of this form of protection are on page 85.

Many post-2013 vehicles (those built to Euro 3 and 5 emissions standards) have variable voltage alternators. Voltage sensing relays cannot be used with these alternators. The *only* successful way to charge auxiliary batteries with such alternators is via a bcd charger. Please refer to pages 24-27 (and for ongoing updates) http://caravanandmotorhomebooks.com/articles/.

Series connection

Series-connected batteries need to be of the same type, amp-hour capacity and general condition. Voltage is additive. Current output (and charge acceptance) is limited by that of the lowest amp-hour capacity battery in the chain.

Battery location and care

With all RVs, do what you can to locate heavy batteries toward the middle of the vehicle. Never locate anything heavy at the extreme rear of a conventional caravan. Doing so may introduce serious instability.

Consider using a slide out battery holder, or cutting a hatch in the floor to gain access from above. Batteries must be securely held in place. They will be damaged if allowed to rattle around.

Charge the batteries via a close-by dc-dc or bdc-bdc alternator charger via adequately heavy cable and an Anderson connector.

Battery installation and ventilation

Vendors' initial claims, to the effect that sealed batteries need no ventilation, were withdrawn shortly after. Battery makers say ventilation is still essential *for all* rechargabled batteries. This includes gel cells and AGMs.

Despite this, several RV makers seemingly know better. They locate sealed batteries in unventilated enclosures, often under the bed. The very batteries installed are likely to carry a warning that ventilation is essential. There are no legally enforceable standards in this area, but there *is* a legal 'Duty of Care'.

Battery compartments *must* be ventilated at their top and bottom. Ensure there are no lips that can trap gases at the top of the enclosure. The (Australian) Clean Energy Council suggests that, for batteries up to 350 amp-hour or so, a couple of vents or holes, each of 50-100^2 mm, at the very top and very bottom of the enclosure should suffice.

Do not house circuit breakers, fuses, switches, or any other electrical device in the battery enclosure. There is no risk in normal operation, but very much one in the event of an electrical fault causing serious overcharging. This is likely to cause a battery pressure vent to open, releasing potentially highly explosive hydrogen and oxygen that, if in a sealed enclosure, can be triggered by a spark.

Battery and cable protection

Some form of safety mechanism must be provided safeguard batteries from gross discharge. This is also required to prevent their energy burning out overloaded cables connected to them, and/or to short circuit; or for a short circuit to form within a faulty connected appliance. As explained on pages 64-65 this best done by circuit breakers, not fuses.

Ideally one major circuit breaker (that also doubles as a main switch) should be included in the main positive cable. It should be located as close as possible to the auxiliary battery, and readily accessible, but not in the same compartment.

Separate smaller current circuit breakers are then installed downstream from the main breaker, to feed various sub-groups such as lighting, air conditioning, water pumps etc.

To save cost some RV makers install a fusible link in place of a main circuit breaker/master switch.

These links bolt into place, but need careful location as they may splatter molten lead some distance if they blow. They are initially much cheaper than a main circuit breaker - but costly over time if faults cause them to blow.

Both main fuse or main circuit breaker should be rated at the lesser of about 70% of the maximum safe current that can be carried by the cable, or 30% more than the highest current normally drawn through that cable. If in doubt, seek the advice of an auto-electrician.

Never insert a fuse or circuit breaker in the lead from the alternator to the battery. To regulate correctly, the alternator relies on knowing the battery voltage. If this is lost, the alternator voltage may rise instantly to 100 volts or more, burning out the alternator's internal diodes etc. Make totally sure that this lead is well-insulated and securely located.

Battery cables & connections

Battery cables are best attached by crimping or clamping - not by soldering. Crimps of this size need a hydraulic tool. Have this done by an auto electrician.

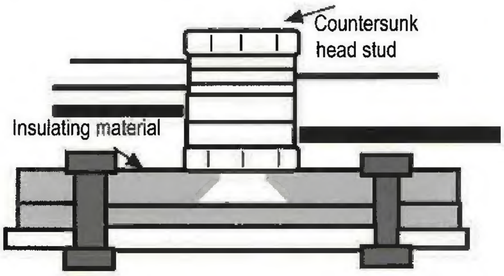
Poor quality battery connectors can cause ongoing trouble. If over-tightened they are liable to crack and break in half.

The best ones are made from oil-impregnated bronze or copper-plated brass. Some have a separate nut and bolt clamp for attaching the cable lug. They are sold by marine electrical suppliers.

Copper plated brass battery connectors. Pic: original source unknown.

Power posts

Many systems have multiple cables attached to battery terminals - with varying degrees of effectiveness and probability of working loose. Also, with the unsealed batteries still used in some major home and property solar systems, the associated cables and terminals may be attacked by corrosive gases.



This power post was made from scrap lying around a workshop.

Avoid the above problems by taking short heavy positive cable from the battery to a fusible link, or circuit breaker, and from there to one or more nearby common power posts, or heavy junction boxes.

Such posts are readily made from scrap material. They are also available commercially.

Connectors such as this are available in any number of sizes and configurations.

If using chassis negative returns, all that is required is a threaded stud securely attached (ideally welded) to the chassis.

Battery terminals and posts need electrical protection. Insulate the posts by plastic or rubber protective boots.

Unless the chassis is being used as a return path there is no need to earth negative leads.

Opinions differ regarding chassis earthing, but it has known side effects, e.g. it can cause electrolytic corrosion in radiators etc. Further, unless really well done and protected against rain and dirt, it is a known and common cause of electrical faults. This book advises against chassis earthing primarily because of these known issues.

This 48-volt battery bank consists of 16 by 235 Ah Exide gel cell batteries connected as four parallel strings. Pic: Author, Broome 2006.

If there are many appliances, take their separate leads from the main power post to a further set of contact breakers, and/or fuses, to sub-circuits.

These may (for example) individually feed lights, water pumps etc. Always feed the fridge via its own heavy cable circuit.

There will be a heavy cable between battery positive and a main circuit breaker, and another between that circuit breaker and a positive power distribution post or connector box. If a current shunt (page 80) is included, it can usefully be inserted in this lead.

The main negative cable from the battery is taken to a negative power post or terminal strip.

Sizing main battery cables

These cables carry the total current of all connected devices and must be sized accordingly. Even though all appliances etc. may not be in use at the same time, assume this will happen when doing the sums.

If an inverter is included, assess its surge current draw as twice the inverter's continuous rating. If an inverter has a continuous rating of 600 watts: the current drawn is 600 watts divided by 12 volts: i.e. 50 amps. Assume at least 100 amps and size the cable accordingly.

When sizing cables, allow a 50% or so more starting current for the fridge - 6 mm^2 is not overkill for runs of two to for metres.

Allow about 100% more for a water pump.

Lighting by and large presents no problem.

Safety precautions

Accidentally shorting battery terminals of a heavy current-carrying cable releases huge amounts of energy.

It can vapourise a large spanner or wedding ring, in a (literal) flash.

This is not a clever thing to do as the molten metal inflicts deep and serious burns. In some cases it may blow a battery apart - splatter one's eyes with acid as it does.

Always wear protective glasses when working with a rechargable battery of any size or kind.

The cause of failure with this battery is unknown - but can happen with any of them - regardless of quality. Pic: original source unknown.

Installing solar modules

Ideally, solar modules in the southern hemisphere should face north, and be tilted toward the sun. Tracking the sun horizontally, but in a fixed vertical plane, may increase their input by 20-30%. At higher latitudes, tracking in *both* planes may increase it by 40%-45%. The gain in such latitudes is thus substantial but, if the array is manually adjusted throughout the day, your risk of falling off a ladder or roof becomes unacceptably high. Automated tracking systems exist, but most are heavy, bulky and costly.

As solar capacity continues to fall in price, except at high latitudes, and/or for the summer/winter set up mentioned on page 76, the loss in solar input through fixed mounting is far more simply (and increasingly cheaply) accomplished by adding more solar capacity, particularly with RVs.

The solar tables on pages 48/49 show output for both horizontal and tilted modules, but all applications described in this book assume close to or actual horizontal mounting. A minor tilt reduces condensation and rain water pooling on their surfaces.

Placing modules

The two solar modules are hinged together and have folding angled legs to enable tilting to face directly into the sun. Pic: Brian Fox (who also made them).

Portable modules enable an RV to be in the shade, but are easy to steal. Further, if you have more than one or two, the connecting cables required are heavy and unwieldy.

The latter problem can be overcome by connecting the modules in series (for a higher voltage) and installing a suitable MPPT regulator (many accept a range of input voltages) at the RV end.

Yet another solution is to have some modules permanently mounted and the remainder carried loose.

Standard modules are readily hinged together with a adjustable legs that enable them to face into the sun at the optimum tilt angle. This also enables them to be stored compactly and more safely.

Self-built folding 120 watt solar modules. Pic (Middle Lagoon, north of Broome) courtesy of Brian Fox.

Connecting loose modules

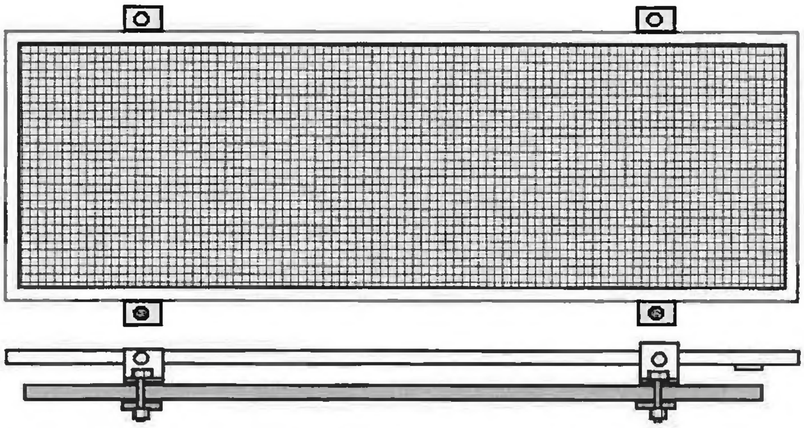
The vehicle ends of the cable/s should be terminated by Anderson connectors. These connectors are overkill, but there's nothing else that will do the job as well at anywhere near the price.

Roof mounting

Roof mounting is cheap, simple and effective. It necessitates the vehicle being in the sun, but a white, heat-insulated and vented roof keeps the interior within a degree or two of that outside. Solar modules add further insulation, enhanced by air space beneath them. Adding a solar-powered fan further increases ventilation. Such fans are stocked by a few specialist suppliers.

Some people have modules roof-mounted but removable when required. This is only for the strong and agile. Typical 120 watt solar modules weigh about 12 kg and their size makes them unwieldy to move. (Lighter ones however are now available.)

Mounting modules on a pop-top roof is likely to necessitate stronger springs or heavier gas struts. Check first with an equivalent weight (e.g. a pillow case full of sand).



Most solar modules have an alloy frame and can readily be located via aluminium or stainless steel brackets. Sketch copyright: caravanandmotorhomebooks.com.

Trailers/fifth-wheeler caravans

Here, an excellent solution is to have some of the modules on the roof of the trailer and the remainder on the roof of the towing vehicle. This enables the towing vehicle to remain in the sun and the living part to be mostly or totally in the shade.

Some battery capacity needs to be in the living part so that power is always available if/when the other half is away. (See Example 7 on page 58.)

Physical mountings (RVs)

Roof-mounted modules need locating with a 15-20 mm air gap beneath. This keeps them cooler, helps heat insulate the vehicle roof, and prevents water being trapped.

There are various ways of attaching modules to the roof, depending mainly on whether the roof can take screws or bolts; and whether any warranty is invalidated if you drill holes.

Space single modules off the roof using brackets cut from (50 mm) aluminium angle.

Multiple solar modules are best attached to a light sub-frame attached to the roof by through-bolts, preferably stainless steel.

Two 80 watt modules run the 60 litre Engel fridge in the author's (since sold) 4.2-litre TD Nissan Patrol. Pic: caravanandmotorhomebooks.com

Another way, commonly used in the USA, is to attach the sub-frame to the *sides* of the vehicle. One US RV builder uses tensioned straps secured at chassis level. It is ugly but it works.

Professional installers often attach the solar module sub-frame with marine-grade Sikaflex. This product remains slightly flexible but holds like you wouldn't believe. Removing it requires a chisel and a lot of effort. Before finally Sikaflexing anything together, triple-check the placement, and also that you can subsequently replace or remove the modules.

Usage	Latitudes <25°	Latitudes >25°
Year around	Angle = your latitude	Latitude + 5°-10°
Summer	Latitude minus 0°	Latitude -5°
Winter	Latitude plus 5°	Latitude + 15-20°

Face modules true north and tilted as shown for maximum yearly input. Or provide adjustable angling for summer and winter respectively.

It is usually necessary to install cabling at the solar module ends before finally securing the modules into position. Ensure you Sikaflex onto something strong - not just a coat of paint!

Uni-Solar and others market flexible stick-on solar modules, but they cost more and, if they fail, you are faced with getting them off. They are handy for steeply curved surfaces but it is usually better to stick them onto a thin alloy plate that in turn can be removed.

If you drill holes, seal gaps with high quality silicon sealant - $3.95 cheapies 'chalk' in the sun. If you stick things down, check the adhesive is compatible with the receiving surface. Petroleum and silicon compounds may affect rubber-based materials.

It may be possible to take cables through an existing vent. If not, an alternative is a cable gland such as Whitworth Marine's Catalogue Number 33516. It is costly but it works.

The website around-oz.com suggests using Clipsal connection boxes with plenty of sealant.

Cabins

Solar modules are available as replacements for materials such as tiles and slates. This may be worth considering if you are building and the roof has (or can be given) the required inclination.

Having modules at ground level is more flexible, and eases installation and cleaning.

Commercial mountings are available, but making your own saves money and is not hard to do. They can be made from galvanised 'C' section roof purlin.

The mountings need bolting down to concrete beams about 400 mm by 400 mm, or 500 mm by 500 mm in cyclone-prone areas.

Overkill for most locations - this frame, holding six 130 watt modules, is one of seven in the big array that the author built for his previous property outside Broome. It was designed to withstand winds in excess of 240 km/h. The main supports are bolted via hi-tensile studs to massive buried concrete beams. Pic: successfulsolarbooks.com.

The array shown here is part of the author's own previously owned cyclone resistant system.

It has an extra heavy (100 mm by 50 mm) version of 'C' purlin and a base (not visible) of reinforced concrete, beams, each 600 mm by 600 mm by 3500 mm, to withstand 240 km/h winds on the ocean exposed and cyclone-prone site.

The X bracing constrained cyclonic wracking forces.

Interconnection for higher voltage/current

Twelve volt systems are assembled from one or more 12 volt modules. Twenty four volts can be obtained by connecting two 12 volt modules in series.

A single 12 volt solar module that generates 5 amps produces about 60 watts. Two such modules connected in series still generate only 5 amps, but now at 24 volts: i.e. 120 watts. Single 24 volt modules are an alternative and are available in higher wattages.

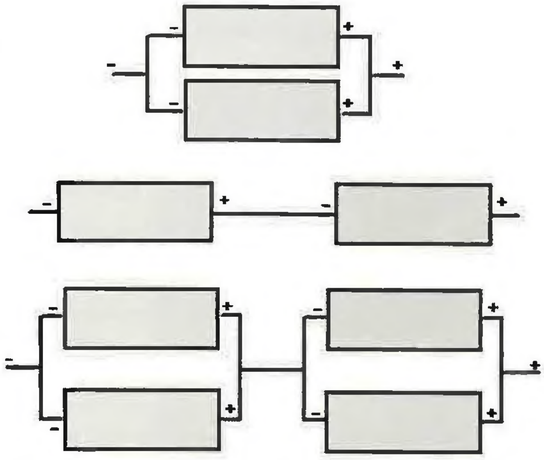
For any voltage you can parallel similar voltage of any wattage modules to increase total current.

Two 12 volt, 5 amp connected modules provides 12 volts at 10 amps - again at 120 watts. Twenty four volt systems can have their capacity increased as shown.

Forty eight volts is obtainable from four 12 volt modules in series, or two 24 volt modules in series.

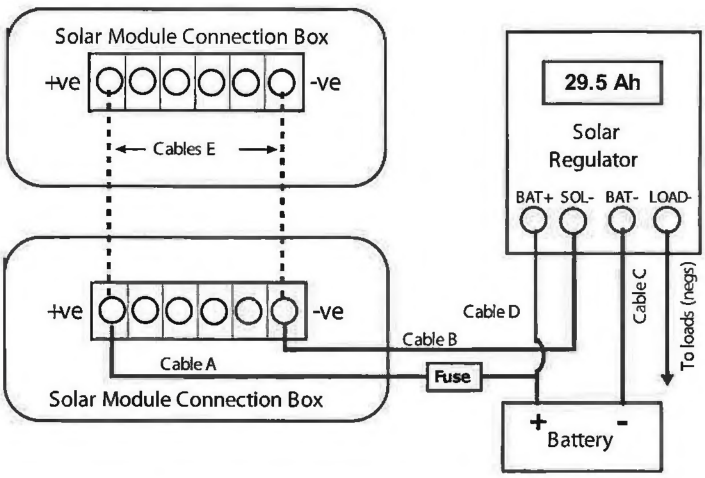
Any combination of similar modules may be connected to provide more amps, or more volts, but however done (and like batteries) they *always* provide the same wattage.

There is no 'magic' way to interconnect them to obtain more power.



Top: parallel connection (current is additive). Centre: series connection (voltage is additive). Bottom: series-parallel connection (both voltage and current are additive.

Solar module cable sizing



Typical solar system connections and recommended (see main text) cable sizes. Sketch: caravanandmotorhomebooks.com

Overall voltage drop is often 0.3 volt, but 0.15 volt is better and ideally across the whole run, from solar modules to battery, including any cable/s connected via the solar regulator.

The configuration shown (left) is a typical solar charging system. It produces 10 amps at 12 volts.

The example assumes that cable A is three metres, cables B and C are two metres.

Cable D carries only a fraction of one amp so 1.0 or 1.5 mm auto cable is fine.

Cables E indicate how to parallel connect further modules.

Their voltage drop too needs to be taken into account, but only for the current flow to Cable A and B.

To avoid complication this has not been taken into account in the example shown here. Cables carrying 10 amp current thus total 7 metres.

The sum

Using the standard formula (assuming 0.2 volt drop) we have: 10 X 7 X 0.064 divided by 0.2 = 5.74 mm^2.

Here, good choices would be 6.0 mm^2 ISO, 10 AWG, or 10 B&S. Any of them results in a very acceptable drop of less than 0.2 volt drop.

Cables E carry five amps across a metre or so. Whilst it is total overkill it is simpler to use 6.0 mm^2 cable for this too. (A comparison of the various cable 'standards' is on page 60).

Series diodes

Solar modules are usually supplied with diodes (electrical one-way devices) already installed within the junction box on the rear of each solar module. Sometimes however, they are supplied for buyers to install if they so wish.

The purpose of these diodes is to prevent batteries discharging through the modules at night, and to a minor extent to reduce the loss when a module is partly shaded. They are advisable where modules are covered for long periods (e.g. against bird droppings, or if the vehicle is stored in a garage) but rarely otherwise.

Typical diode (shown here larger than typical size).

The diodes introduce a voltage drop that mostly loses more energy than the diodes save. A low-loss 'diode function' (that does the same job) is built into solar regulators anyway.

These diodes are also prone to failure. If they do fail, and you wish to replace them, spares can be obtained from stores like Altronic, Jaycar Electronics for under $1.50; or from specialised solar shops for prices up to $25.

If possible, do this yourself. It is not unknown for people to be charged over $100 for supplying and fitting just two of them.

Sailors commonly cover their solar modules when not in use, to protect the modules against corrosive bird droppings. By doing so they risk the batteries discharging into the modules over time. Diodes safeguard against this. Apart from that, there's no point in retaining (let alone replacing) them.

Earthing

Particularly whilst driving and in windy conditions on hot dry days, solar modules are prone to acquiring strong electrostatic charges. These attract dust, and in extreme situations can damage the modules electrically. With large arrays there is also a risk of damage from lightning.

Modern vehicle tyres are partially conductive so the chassis is effectively earthed. With RVs this enables electrostatic charges to be removed, and lightning damage reduced or eliminated, by earthing the modules' frames to the vehicle chassis. Most modules have an earthing point for this purpose.

For solar arrays that operate above 120 volts dc (i.e. Low voltage) the module frames must be earthed in such a way that if one module is removed no other component's earth is compromised. This is particularly important for systems with non-electrically isolated inverters.

The module frames must also be earthed for solar modules that have ac micro-inverters that have an output exceeding 50 volts ac.

The requirement for the above are in the latest version of AS 4777 (Grid connection of energy systems via inverters), and AS/NZS 5033 (Installation of photo voltaic [PV] arrays).

The frames should be earthed to the vehicle chassis, via not smaller than 4 mm^2 cable. Fixed installation should be earthed via one of those copper (or copper-plated) earthing rods made specifically for this purpose. They are stocked by electrical wholesalers.

Opinion has been historically divided as to whether to earth the neutral solar feed from the array.

If it is earthed, nearby lightning strikes may cause a high voltage to be induced in the unearthed cable (relative to the other), thus damaging the array and solar regulator. On the other hand, if unearthed, equal voltages are induced in each cable, so whilst there is no potential difference between them, they may then be both at a momentarily high voltage relative to earth.

Low voltage solar array cabling is double insulated, but at the date of publishing, there was no requirement to earth either of the dc conductors.

Installing the regulator

The solar regulator needs locating where its read-out can easily be seen. A good way is to mount it on the outside of a cupboard, with the wiring concealed within. It will need some air flow around it.

Regulator wiring is reasonable straightforward but here is yet another trap that tends to catch out people who know about electrics - but not about solar regulators.

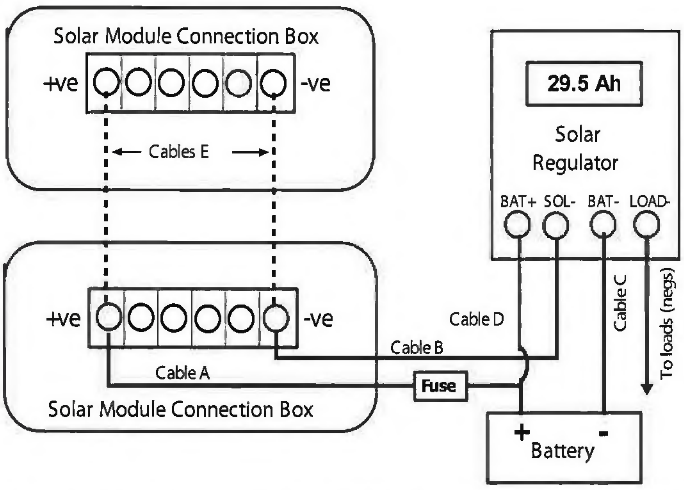
In order to set the correct charge rate for the battery, a solar regulator relies on knowing the exact voltage across the battery. This is usually done via one or two light voltage sensing leads.

The Plasmatronic PL solar regulator, for example, must have the cable from the solar module positive run *directly* to the positive battery terminal. A voltage reference lead is then *run back* from that terminal to the B+ terminal on the solar regulator - as shown correctly in the main connection diagram - below left.

It might seem to make sense (but does not) to run that main solar feed cable via the solar regulator to the battery (as shown on the 'faulty' connection drawing) as this saves that (light) cable run.

Or where two such cables are required, as with some regulators, to omit both.

Plasmatronics PL 20 solar regulator. Pic: caravanandmotorhome books.com.



*Above - correct installation of a Plasmatronic PL regulator. Cable 'A' **must** be wired exactly as shown. If wrongly wired (below right) the battery will always be undercharged.*

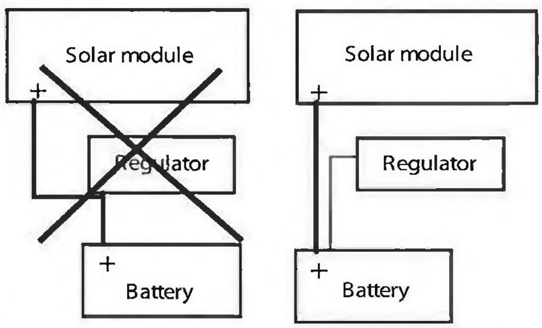
If you do so, however, the voltage drop on the positive cable between the module and battery causes the regulator to 'see' a voltage closer to that of the solar module, and thus higher than that of the battery.

The thinner the cable, and the greater the distance from the battery, the greater that voltage difference will be.

This higher signal voltage causes the regulator to perceive the batteries are at a higher voltage than they are. The regulator cuts back the charge accordingly.

Other regulators may require this of both positive and negative leads via terminals provided specifically for this essential function.

If the regulator really *is* meant to be wired as shown, and a few are, locate the regulator as close as is feasible to the battery, and make sure you have no more than 0.1 volt drop across the cable from the regulator to the battery. It is essential to follow the solar regulator maker's instructions. Cable sizing for regulator circuits is covered on page 77.



Faulty connection of Plasmatronic PL (left), correct connection (right).

Load measurement

Some solar regulators monitor both solar and load current. This may require returning load negative leads to the battery via the regulator's 'Load' terminal (instead of directly to the battery).

For this to work correctly, appliances must not have any other form of earth return. This can present problems as some appliances, especially fridges with metal frames, have negative connected internally to that frame. If that frame is earthed their current draw will be *recorded* as less, or barely at all, because there are now two parallel negative paths - one via the negative cable and the other via the chassis.

Most regulators only monitor loads within their charge rating (some are limited to less: e.g. the PL 20 monitors 20 amps, but the PL 40 monitors only 7 amps, and early PL 40s only 5.0 amps). This is a major limitation if one wishes to monitor the current draw of a big inverter, or the input from the alternator, or from a big battery charger. The solution is to use a current shunt to measure that current draw.

Current shunts

A current shunt consist of one or more short metal strips in series with a main battery lead. A shunt introduces a slight resistance that causes a small signal voltage to be developed across it. This voltage is directly proportional to the current flowing through the shunt.

Typical current shunt. This one can handle up to 200 amps. Pic: caravanandmotorhomebooks.com.

The signal (typically 50 millivolts at 200 amps), is thus an indirect but accurate measure of that current.

The shunt is usually connected to the solar regulator (or battery monitor) via an adaptor, typically via a pair of light twisted wires. Ones made recently however may be via a USB cable.

A shunt is not *overly* difficult to install, but there are a few traps. Unless you are reasonably conversant with electrical practice it is probably better to have an auto electrician do it for you.

Positive versus negative sensing

The shunt may be installed in either the positive or negative battery cable. If, however, you have it in the negative side of a system that uses the chassis (even accidentally) as a negative return, some part of the current may pass through the shunt, and some through the earth return of equipment that has its negative connected to earth. That current bypasses the shunt and thus not registered. This can occur, (much as noted above) with an Engel fridge if it is located by metal tie downs to the vehicle chassis.

Where a current shunt is used with an external energy monitor (as opposed to the in-built monitoring facility of a solar regulator), all charge and load current must pass through that shunt, requiring all inputs and loads are normally taken to the *non-battery* side of the shunt.

If however using a shunt in conjunction with a solar regulator that has its own in-built monitoring, you must take the solar feed (only) to the *battery side* of the shunt. This is usually, but not invariably, made clear in the solar regulator instruction manual. It *must* bypass that shunt otherwise the solar input will be registered once when it passes through the regulator and again when it passes through the shunt. The regulator monitor will thus show it incorrectly as doubled. This can result in some users wrongly believing the system has twice the solar input than it actually has.

If desired and where relevant, the alternator charge to the auxiliary battery can also be registered on the energy monitor by taking its battery feed via the shunt.

For system with variable voltage alternators, all negative return cables (including the auxiliary battery negative) must be connected *to the chassis end of the starter battery negative cable - not* the starter battery negative terminal. An incorrect connection here results in the auxiliary current draw not being monitored by the vehicle system and may lead to a flat starter battery. See also page 60 regarding earth returns.

Installing the fridge

A fridge's energy consumption, and its ability to cool in extreme heat, depends substantially on how well it is installed. An RV fridge needs installing such that, apart from the door, it is *totally* sealed from the RV's interior. Few installers do this properly.

All fridges must be level and out of the direct sun. The wall behind them should be heat insulated. There must be provision for cool air at their base and for this air to be *directed* over their cooling fins.

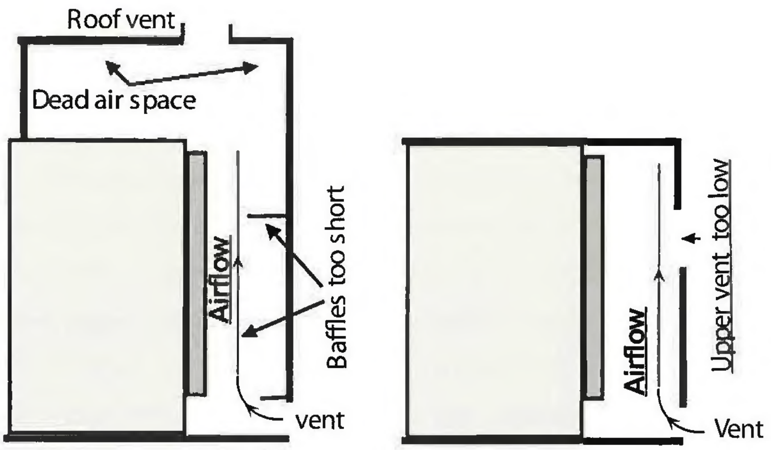
Some fridges dissipate heat from their sides. These need a 50 mm air gap either side, plus provision for cool air to flow from their base and up their sides. Whilst not always possible, the rising heated air really needs to be vented to the outside, ideally at roof level.

The illustrations show the salient points. Details will vary from fridge to fridge. In particular, ensure that cold air is vented such that it flows *only* through the cooling fins, rather than bypassing them.

Baffles (see sketches below) assist a great deal. They can be made from cardboard, sheet alloy, timber etc and installed such that they extend to within a centimetre or two of the fins.

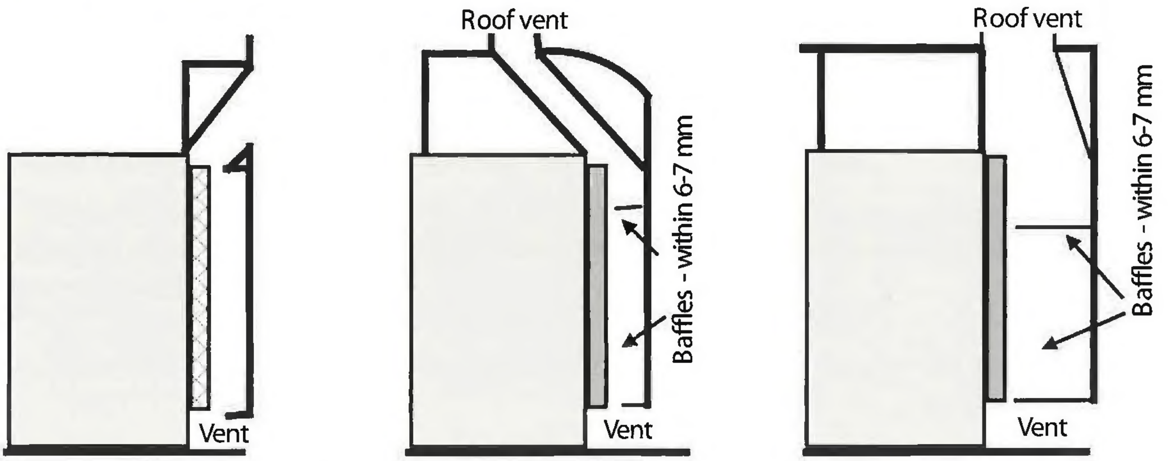
Cooling problems whilst running on 12 volts, but less so on 230 volts, are almost always due to inadequate cable size, bad connections, or both. Problems tend otherwise to be caused by poor ventilation, faulty door seals, and (for gas fridges) out of level installation or operation.

Gas/electric fridges *must* be connected via adequately sized cable and that is much thicker than usually found. Most fridges are have at least 0.5 volt drop and 1.0 volt is not uncommon. Limiting voltage drop to 0.15 V is desirable, with 0.2 V as a maximum.



Left: too short (or lack of) baffles causes the incoming cool air to mainly bypass the cooling unit. Also, rising hot air is trapped, thus hindering air movement through the upper vent.

Right: the upper vent is far too low, trapping hot air above it. The vent ideally needs to be above the fridge level - and a small fan used to extract the hot air. Baffles too are needed.



Above: How to install fridges correctly. An extractor fan (run directly from a 5 watt solar module) further enhances cooling performance. Baffles really do help yet are rarely used. All pix: copyright caravanandmotorhomebooks.com

Achieving this often necessitates replacing the originally-supplied fridge connecting cable as that *alone* may introduce over 0.2 volt drop.

A further cause of inadequate cabling is that the larger versions of three-way fridges draw a lot more current than many people realise. Even 120 litre units draw 12.5-15 amps. Large three-way fridges may draw over 25 amps (at 12 volts). This necessitates heavy cable.

Example 1

This relates to a compressor type fridge in a motor home. The fridge draws 5.0 amps and is sited three metres from the main battery connection. The total conductor length (wiring is twin conductor) is thus six metres. Applying the formula, for 0.15 volt drop gives: 5 X 6 X 0.0164 divided by 0.15 = 3.28 (mm^2). Here, 4 mm^2 results in a drop of less than 0.15 volt.

Example 2

Complications set in where an electric-only fridge is to be run from a caravan battery - yet those batteries are charged from the alternator as well as from solar.

Have as large a proportion as possible derived from solar, and as heavy a power cable as feasible between the car and the caravan. Here 13 mm^2 or 16 mm^2 cable is far from overkill.

Better still is to install that heavy cable and also a 12 volt to 12 volt dc-dc (or bcdc) converter or charger (pages 22-27) as close to the caravan batteries as possible. This ensures optimum charging and also provides optimum voltage for the fridge.

Almost all fridges can have their cooling performance improved and energy consumption reduced by following the advice in this chapter. Sometimes dramatically so.

Installing an inverter

You may legally do the 12/24 volt wiring yourself, but if the inverter is to connect into fixed 230 volt wiring, that part of the job must be done by a licensed electrician.

Big inverters may draw as much current as do light starter motors. They need to be housed as close to the battery as is feasible and connected by heavy cable.

To calculate cable size, take the maker's *continuous* power output for the inverter and add at least 50%. For 12 volt systems, dividing by 11 results in amps (and allows for internal inverter losses). For 24 volt systems, divide by 22. Size the cable, so as to result in no more than 0.2 volts drop, using the conversion chart and formula (pages 60-62).

Do these calculations before finalising plans: the cable is likely to be large. You need to make sure there is space for routing it.

Protect the cable by including a *manually* re-settable circuit breaker or fusible link (pages 64-65) as close as possible to the battery, and rated at 30%-40% higher than the peak current draw of the inverter.

Battery/inverter cables must also be protected against breaking, working loose, or being damaged.

If necessary have the cables made up by an auto electrician.

Before finalising plans, check the inverter's noise level: many have cooling fans. You may need to house the inverter in a sound-insulated (and ventilated) enclosure. Or locate it elsewhere.

Connection sequence

Connect the 12/24 volt side by following the inverter maker's installation sequence. If none is given follow this sequence carefully:

1. Ensure that the circuit breaker is 'OFF' (or the fusible link is *not* in place).

2. Ensure the inverter is 'OFF'.

3. Connect the negative (black) lead to inverter negative.

4. Connect the other end of that negative lead to battery negative.

5. Connect the positive (red) lead to inverter positive.

6. Connect the other end of the above lead, via the circuit breaker, or fusible link, to battery positive.

7. Re-check 1-6 and fix immediately if incorrect.

8. If all is well, insert fusible link, or click circuit breaker to 'ON'.

9. Switch on and check that all indicator lights etc. are as per the maker's instructions. Then plug in a 230 volt appliance and check that it works.

If it does not work, try the following:

Some inverters switch on automatically whenever a load is applied. The threshold of this setting is adjustable and it may have been set too high. Try plugging in a heavier load.

If the inverter now works, reconnect the lightest load you are likely to use and adjust the inverter threshold setting so that the inverter switches on when this load is switched on, and switches off when the load is switched off.

Installing water systems

Water resists being pumped through pipes. The resistance reduces pressure and flow and wastes a great deal of energy. Water's resistance to flow is akin to that of current flowing through an electrical conductor, only much more so. A 12 mm diameter hose needs *five times* as much power to push water through it as does a 19 mm diameter hose. This is not of huge importance in the average RV but becomes so in large coaches. It can be truly significant in big cabins and even more so with irrigation systems.

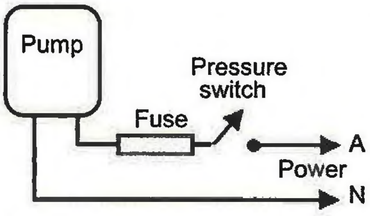
Water also dislikes turning sharp corners. Where feasible have sweeping curves rather than right angle bends. For drinking water, and water for cooking, use food-quality hose. Use stainless steel hose clips.

Water pumps draw about twice their running current (typically of four to six amps) for a second or two whilst starting. The supply cable should be rated for this starting load (i.e. 8 to 12 amps), as pumps are prone to stall and overheat if voltage is low. They may even burn out. Install a blade-type fuse close to the pump. Try a 10 amp slow-blow type first. If this blows frequently, replace it by a 15 amp normal type.

Most RV pumps have an pressure switch and are connected as their makers show.

A few pumps (made mostly for irrigation) need an external pressure switch. These switches can be located anywhere between the pump and the tap/s.

In either case include a remote on/off switch in a readily accessible location so that the pump can be turned off if necessary for any length of time. An alternative is to feed it via a circuit breaker that doubles as that remote switch.



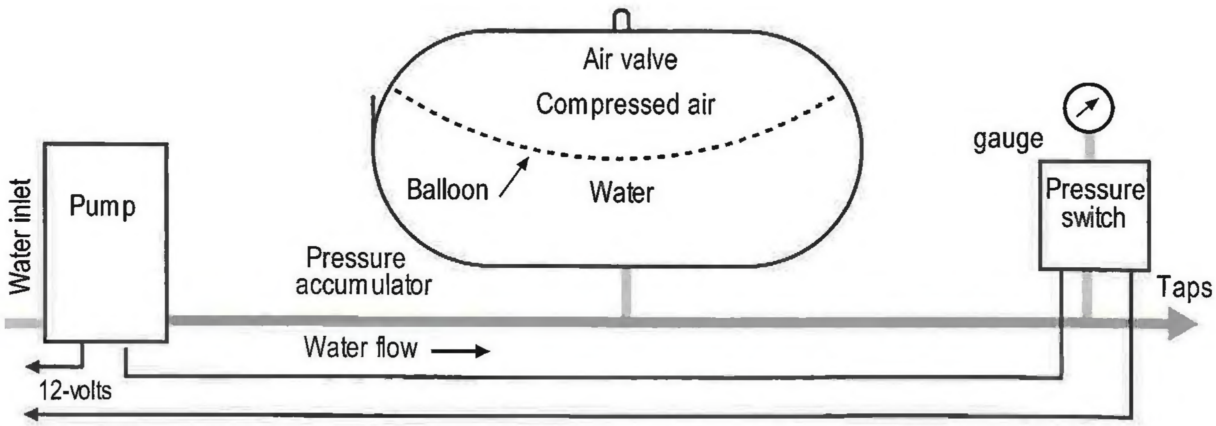
Installing a remote pressure switch.

Replacing an internal pressure switch costs much the same as buying a new pump. If one fails it can be bypassed and replaced (externally) by one of the really good ones made for irrigation use. They last for ever and cost only a third or so the price of a replacement pump. They can be adjusted to work over the required range: 140-350 kPa (20-50 psi). Connect as shown (left).

Pressure tanks

Some pressure tanks have a separate water inlet and outlet, necessitating two corresponding hoses. Others have a single outlet and require a tee connector.

With either, the pressure tank, pressure switch, and (optional) gauge can be located and teed off anywhere that is convenient between the pump and the first tap. It is just fine, for example, to have the pressure tank and pump underneath and at the rear of the vehicle (or outside a cabin), and the pressure gauge in the kitchen connected via a small diameter pipe (any size over a few mm will do).



Pressure tank installation is very flexible. The tank, pressure switch and gauge may be teed off anywhere between the pump and the first tap. Illustration copyright caravanandmotorhomebooks.com.

Installing a voltage sensing relay

Where a fridge or the RV system is to be powered by a battery charged by a conventional alternator (in practice any that never drops below 12.7 volts whilst driving) it is essential to set this up so that the starter battery is assured of starting priority, and is protected against accidental discharge.

This used to be done by a heavy current manual switch, or a basic relay that linked batteries when the ignition was 'on' and separated them again when it was turned off. It did not, however, provide automatic starter battery charging priority. This could result in the starter battery being discharged by a 'flat' auxiliary battery suddenly being connected. Or by forgetting to turn it off.

This was later (1980 onward) overcome by a voltage sensing relay that isolates the auxiliary battery from the starter battery (and alternator) until the starter battery is recharged to 13.2-13.5 volts, typically inside a minute or two. The relay separates the starter battery again if its voltage drops below the 12.5-12.7 volts needed for cranking.

The example shown (right) has an optional connection that enables the auxiliary battery to be paralleled across the starter battery manually to aid starting (if extra current flow is required).

Another recently introduced unit, from Intervolt, is programmable for different pull in and drop out across a useful range of voltages.

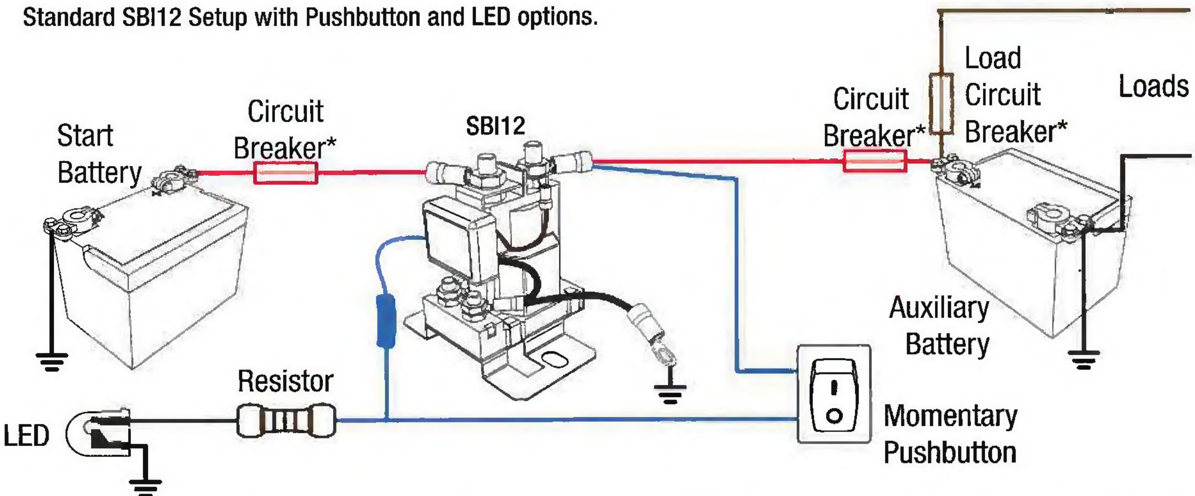
Voltage switching relay, links batteries only when the starter battery is adequately charged. Pic. redarc.com.au

Variable voltage alternator issues

These relays cannot be used with the mainly post-2013 vehicles that have variable voltage alternators as their voltage drops below the relay's hold in voltage every time the brakes are applied or the accelerator pedal released whilst (say) descending a hill. (Pages 22-27).

Vehicles with these alternators can *only* charge an auxiliary battery by using a specialised battery to battery dc alternator charger. These have starter battery charging protection inbuilt.

Standard SBI12 Setup with Pushbutton and LED options.



External LED status indicator, mount on dashboard.
Resistor only required if pushbutton and LED are both installed.
Resistor values:
12V = 1kΩ or 24V = 2k2Ω
(Resistor NOT required if 12V LED is used)

*** Redarc recommend Manual Reset Circuit Breakers however fuses are acceptable.**
When using fuses make sure that the fuse makes a good low resistance connection.
Circuit Breaker/Fuse ratings are dependent on the type of installation and the size of the loads.

How a typical voltage sensing relay is connected. The (blue) cables, push button, resistor and LED are needed only if there is a need to connect the auxiliary battery manually across the starter battery to aid starting. Drawing: redarc.com.au

Compliance issues

As advised in the 2012 edition of this book, vehicle regulatory authorities (especially in Queensland) have tightened up their inspections, particularly of self-built RVs, and imported fifth wheel motor homes and fifth wheel caravans. It is not possible to go into full details as several such matter were before Australian courts of law at the time of printing this edition. Because of this only generalities can be discussed.

Readers planning to purchasing any self-built RV, and new and (particularly) second-hand imported fifth wheel caravans are very strongly advised to make 100% sure that they really *do* meet all Australian requirements. Many of their owners believe they are fully compliant. Very few are.

Until 2011 or so, some inspecting authorities accepted written declarations that the required Standards had been met, on the reasonable assumption they were valid: but some were not. This resulted in their being approved as complying and registered accordingly. As later reported in Federal Parliament, many imported prior to 2010 were found to have false or forged certification.

This raised major problems, particularly when the vehicles are presented for re-registration. It is now totally known by regulatory authorities that some compliance certificates are invalid. Most now check these units very thoroughly, particularly their electrical and gas installations, and also that their overall width and rear overhang do not exceed legal limits.

Although assurance of compliance may be written into the sales agreement, even *that* may not guarantee that all required work has been or will be done. Discuss the electrical requirements with a local licensed electrician experienced in RV work (the requirements differ substantially from domestic practice) and follow their advice. Then have that electrician physically check the vehicle. Have a similarly experienced gas fitter check that side of the work.

Have the vehicle weighed *in your presence* on a certified weighbridge and obtain a printed certificate. Do not for one moment accept *any* previous certificate, no matter where from.

The major concerns are non-compliance with the stringent requirements of AS/NZS 3000:2007 and AS/NZS 3001:2008 relating to mains-voltage wiring and related obligatory protection devices, gas installation, overall width (including any awning), rear overhang and often overweight.

The reason to take this so seriously is that the necessary work to ensure compliance can be hugely costly. It can mean total rewiring, replacing springs and shock absorbers and even the entire braking system. If over-width it may be impossible to achieve compliance and be thus rendered unsalable.

Whilst the vendor that sold the unit to you is legally liable, it has been alleged that at least one went into receivership to avoid payment.

Whilst outside the scope of this book, there are also likely to be issues of gross overweight, and suspension that is unsuitable for Australian roads.

For further information re this, see Articles at: http://caravanandmotorhomebooks.com/articles/

Electrical non-compliance

Non-compliance also (and particularly) often affects RVs that have been *privately* imported from the USA. In most cases (even if using a 'facilitator') the legal buyer is the person who pays the bill.

Almost all such RVs are 'converted' by adding a 230 volt to 120 volt transformer, so the RV's 120 volt wiring and appliances can be used. This allows the original buyer *(only)* may legally use that vehicle.

It does *not* however confer electrical (or other) compliance. Such RVs cannot legally be sold (nor even given away) unless brought into 100% compliance.

Very few owners of these vehicles are aware of this. They believe totally, but wrongly, that their RV is 100% compliant. It is not.

It is easy to detect this. If the vehicle has any 120 volt appliances it cannot, by definition, be compliant. The reason why it cannot be compliant is because, in Australia and New Zealand, all RVs must meet relevant Standards. None allow any domestic 120 volt appliances to be sold. Such appliances are in any case designed for 60 Hz operation (not 50 Hz) and may overheat or misbehave in any manner of ways. Nor can the existing 120 volt wiring, switches or power outlets be used to carry 230 volts.

In such cases the RV's entire 120 volt system (including cabling circuit breakers, switches, socket outlets etc) *must* be replaced. This may require the removal and subsequent replacement of the RV's entire outer skin. Also to be replaced is the 120 ac to 12 volt dc converter invariably installed.

Electrical converters

Until recently used mostly in US and Canadian RVs, these units are intended to power 12 volt lights and appliances via mains voltage power on the assumption that users will overnight primarily in caravan parks where such power is available and used. They are now however being routinely fitted to RVs worldwide. As privately imported RVs with originally 120 volt systems will have 120 volt converters, these too will need to be replaced.

A converter is a large and heavy step-down transformer and rectifier. It supplies the 12 volt system with 30-50 amps at an unregulated 13.6 or so volts dc. All of an RV's 12 volt bits normally run directly from this converter. A typically small 12 volt battery is included, but that battery *does not* supply power in normal usage. Only in 'emergencies' (defined presumably as being the absence of mains power) is the battery automatically switched into use.

Many converters do not incorporate a battery charger as such. Instead they use that 13.65 volt output primarily to maintain charge in a battery that is *already* fully charged. Its main purpose is to protect the battery between infrequent RV uses. The available 13.65 volt maximum is too low for meaningfully charging even the small battery typically supplied, let alone the 150 to 300 amp-hour capacity required for free-camping. It will partially charge that original battery but will take a day or more to do so.

If only caravan park usage is in mind, an imported RVs' 120 volt converter can be replaced by a locally available 230 volt equivalent. If, however, that imported RV is intended to be used away from 230 volt power, replacing the converter by its 230 volt equivalent will not suit that need.

It is feasible to replace the converter by a good quality three-stage battery charger run directly from 230 volts. The battery too will need to be replaced, but this often presents the problem of where to find space to locate the much bigger one/s required. Structural reinforcement may be needed to carry the considerable extra weight - unless a (much lighter) lithium-ion battery is used.

There is, however, likely to be a further associated problem with the above.

Converter associated wiring issues

Knowing that a converter's output is usually an unregulated 13.65 or so volts (almost one volt higher than from a 90% charged deep cycle battery), many RV makers install thinner cable accordingly. Whilst replacing that converter by a high quality battery charger may fully charge the battery, it cannot compensate for that voltage drop across cable inadequate for conventional 12 volt battery use.

It will thus be necessary to upgrade all main charging circuit wiring, fridge and pump wiring etc.

An alternative is to use lithium-ion (LiFePO4) batteries. These charge to 80%-85% from 13.65 volts and rarely drop below 12.9 volts in typical RV use.

There is one positive: the USA is not particularly energy-conscious so the globes generally fitted to their RVs are often energy-gobbling incandescent units of about 36 watts each. These globes draw so much current that the original wiring can be relied upon to be adequate if they are replaced by LEDs as they close to 80% less. A great deal of energy is saved too.

Fixing problems

A probable 90% of all 12/24 volt electrical problems are directly due to too-thin cable, and/or loose or corroded connections. Many twelve volt fridges suffer from this. Fix these problems before adding solar or you will not know where lies the cause of any future problems. Other common causes of excess voltage drop are faulty fuse holders (see below re fuses) and poorly made earth connections in those RV systems that have earth returns via the vehicle chassis.

Fuses blow after a few hours, yet there is no apparent fault

The fuse rating should be 50% higher than the maximum current normally drawn, or 75% higher where it's very hot (as in central Australia or Arizona, or above the exhaust pipe, and especially if both). Electric motors draw high initial currents and need 'slow blow' fuses.

The cause may also be loose or corroded fuse holders, or poorly crimped lugs heating up the fuse and thus causing it to blow. Check for heat under charge or load. Ideally replace all fuses larger than 15 amps, and also their holders, by the high quality (and much physically) larger units shown on page 64. There is also a known problem with low quality blade fuse holders partially melting or burning out.

Batteries only last a year or so

This is usually due to chronic overloading, but can also be a result of voltage drop, as a direct result of the above, resulting in chronic under-charging. Overcharging can also wreck batteries (especially AGMs) but otherwise uncommon except where they have been left permanently across a cheap mains charger.

A battery's life is also a function of its temperature. If possible locating a auxiliary battery under the bonnet should be avoided. Likewise it is essential to keep batteries out of the direct sun.

Batteries appear to fully charge but are flat soon after a light load

This almost always indicates that the batteries are badly sulphated, i.e. inactive material flakes off the plates and drops to the bottom of the cell. This slowly build ups and may eventually short circuit the plates. If/when it does, it results in almost instant battery failure.

Sulphation is caused by chronic under-charging, or by leaving batteries discharged over time. So too does battery age. Sulphation shows up as a high charging voltage after some minutes, or sometimes longer, even though the batteries remain deeply discharged. There is an *apparent* charge, but it exists mostly on what little remains of the surface of the plates. The battery voltage may well seem fine for a few minutes but then drops rapidly.

I need to add a centimetre or two of water to my big property systems (wet cell) batteries every second month. Is this normal or are they being overcharged?

It is normal. All such batteries gas once beyond 70-75% charge. This causes a small amount of water (but not acid) to evaporate. *Not* needing to top them up by a centimetre or two every 8-10 weeks is almost always a sign of chronic *undercharging*, resulting in progressively increasing sulphation (see item above).

Batteries gassing after installing solar

Gassing begins above as noted above - when conventional chargers begin to taper off. It was less often encountered (or was mild) prior to the multi-stage charging that enables batteries to 100% charge.

Gassing can be appreciable and even loud. It often worries people not accustomed to it. As long as water level is maintained, gassing is beneficial. *Unless* they gas toward the end of charging, batteries are undercharging. It occurs also in sealed lead acid batteries but is contained and not usually audible.

Solar charge reduces in the afternoon

This is normal. As batteries increase in charge, the solar regulator reduces the charging current accordingly. With most well-designed systems this typically happens around 2-3 pm on sunny days.

Solar charge is sometimes well above the modules' claimed maximum output

This is common with installations close to the sea, along inland lakes and sandy areas etc during times of bright sun, and also low scattered sun or haze. In such areas, the solar modules receive direct sun via gaps in the cloud, plus sunlight reflected upward from the water or sand and then down again from the underside of white cloud or haze. This typically lasts for a few minutes, but, during that time, the solar input may increase by 20-30%.

Solar charging appears be twice that expected - far higher than that claimed by the solar modules' vendors. Why do not others I talk to about it experience the same: or do I have an exceptionally good installation?

No - you have a wiring fault. The input is likely to be as expected, but is being recorded twice. This is a known issue and usually occurs where the monitor is part of the solar regulator. These automatically register and display the solar input as it travels through the regulator. If the system and the installation includes a current shunt and the solar input is routed (as with other inputs and outputs) through that shunt, that solar input is registered there also, and *added* to the existing readout. In your installation, the solar input must be connected directly to the battery, not via the shunt. See also page 79 regarding this.

Halogen globes fail prematurely

The usual cause of apparently failed halogen globes is tarnished pins. Cleaning with fine emery paper usually fixes them. Also, halogen globes are damaged if used whilst battery charging because they are designed to run at 11.8-12.2 volts. Rather than addressing this problem, consider replacing the globes with the far more efficient LEDs - see also pages 36-38.

Overcharging/over-voltage from solar modules with regulator connected

Usually an urban myth, or a low quality regulator. Twelve volt modules may generate over 20 volts, but the regulator reduces and adjusts this for optimum charging. Given an adequate and correctly adjusted soar regulator, a system may be left running for years on end (excepting that some makers prefer stored AGMs to be left fully charged - and then charged again only when they have fallen to 60% or so - typically after 6-12 months). Where relevant, you need to top up a battery's water level every two to three months.

I live in a dusty area yet cleaning and polishing the glass seems to cause the dust to build up quicker and even worse

You are adding to the problem by creating a static charge through polishing. Static is also generated by dry wind blowing over the glass. Check that the metal frames of the modules are all thoroughly earthed (advisable for lightning protection anyway). When cleaning the modules, wash them using water containing a teaspoon or two of detergent (an anti-static agent); then rinse them with clean water that also has a teaspoon of washing up detergent. Allow to air dry. Do *not* polish them.

I am bothered about a TV program in which a participant claimed that live solar arrays can kill people. How can I protect against this?

The program segment related to risk with grid connect systems where solar arrays may run at several hundred volts. But most RV solar arrays run at only 18-30 or so volts dc. Such low dc voltages may give a slight tingle but the main risk is of falling off the 'van roof in surprise.

Anything much over 50 volts dc or so has the potential to kill or injure. Australian law allows unqualified people to work on voltages of up to 120 volts dc, but that voltage is far from danger-free. To be safe, before working on the system securely tie a blanket or sheet over the modules thus preventing any voltage output.

Is it really true that Victoria-built RVs can have the 230 volts connected by non-electricians and that no Electrical Compliance Certificate is required. If so why and how?

For reason that (to me) defy sanity, the Victorian authorities do not classify RVs as Electrical Installations. They do have to meet Australian standards - but the wiring etc may legally be done by unlicensed workers. Nor is routine inspection or certification required.

Living with solar

Once set up, a well designed and installed solar energy system needs little attention except for topping up (non-sealed) batteries with distilled water. This is likely to need doing every second month or so during the summer, and every third month or so during the winter. If no topping up is required the batteries are being undercharged. The trend is very much toward sealed batteries however, so topping them up is becoming an example of what old people did.

Solar modules do not have to be squeaky clean. Even when mildly dusty they lose only a few percent or so of their output. In non-polluted areas, occasional rain does the job, otherwise (unless they are very dirty) use a bucket of clean warm water and a few of detergent. Rinse with clean water - and leave to air dry. Do not wipe them dry, and particularly *do not polish them.* Doing either builds up a static charge that attracts and retains dust. (See also the related item on the previous page.)

Typical indications

A correctly working self-sufficient system may not work as you might at first expect. It may not, for example, appear to produce any more power on long bright summer days than in spring or autumn.

What is happening is that during the summer, more energy is available than you may need. If it is not used, the batteries will become fully charged earlier in the day. When this happens, the solar regulator reduces the charge. In practice, the energy coming in is usually 10%-15% higher than that going out. The disparity is due to charging/discharging losses.

A self-sufficient system working correctly will behave something like this. Before sunlight strikes the modules, and with nothing switched on, the battery voltage is likely to be 12.4-12.6 volts.

Part mobile home, part mobile office, this converted coach (owned by Eric Brandstater) has one of the best self-installed solar systems I have yet seen. It puts most professional jobs to shame. The coach travels Western Australia most year-around. If you see it (it's bright yellow) ask to have a look. Pic: Author 2006. (One week after this photo was taken, in 2006, a bush fire wiped out all the background for about 30 km). Pic caravanandmotorhomebooks.com.

As the day progresses, the battery voltage will rise. Once the sun is fairly high in the sky, the charge rate will remain substantially constant.

When the maximum preset charging voltage is reached (which may be as high as 15 volts), the regulator will either hold it at that for an hour or two, or more likely reduce it to about 14.4 volts.

If the latter, the charge current will fall to somewhere between half and two-thirds of that previously. This period (called absorption) typically lasts for a couple of hours, by which time the batteries will be very close to 100% charged.

The charging voltage then reduces again, this time to 13.2-13.6 volts depending on temperature and battery type. This is known as 'floating'. Ideally this charge balances the battery's internal leakage and compensates for minor loads (e.g. electric clocks etc). As long as it is topped up with water from time to time (where relevant) a lead acid deep cycle battery can be left on float charge indefinitely via a high quality solar regulator. Mains float charging *necessitates* a high quality three stage charger.

The lowest voltage indication (usually during the evening) is likely to be around 12.0 volts whilst the batteries are under normal loads. A microwave oven will however (and for some length of time) pull battery voltage as low as 11.4 volts. This is fine as long as the voltage comes back to over 12 volts within an hour or so. A deep-cycle battery is 50% discharged at 12.25 or so volts - but that is its rested voltage after 12-24 hours. It is likely to be lower under even a light load.

As a very rough guide, charging is usually satisfactory if the on-charge battery voltage exceeds 14.4 volts in typical RV usage by early to mid-afternoon on most days. The system should also go into 'float mode' shortly after. If it doesn't, check that the regulator is set up correctly. If it is, and the batteries are known to be in reasonable condition, increase solar module capacity. This also happens if the battery capacity is too large.

As stressed elsewhere in this and my other books and articles, most cabin and RV systems have too little solar capacity and too much battery capacity. Ideally add more solar, but if that is not feasible and battery capacity is truly excessive it is often beneficial to reduce it. The reason is that large battery banks have substantial internal losses, so some part of the otherwise stored energy is lost. A smaller battery bank has a better chance of being fully charged.

Training visitors

Early editions of this book emphasised that you'll need to train city visitors to turn off unnecessary lights, take short showers, leave their hair-dryer in the travel bag, turn the TV/DVD (or other such electrical acronyms) off at the power outlet, and forgo using the microwave to thaw out frozen chickens - otherwise power usage is doubled, or more.

Experience over the years however showed that asking that energy be conserved does not work with city-bred teenagers, many city bred older people, and almost all caretakers. At best, a 15 minute shower becomes 'only' ten minutes.

We partially resolved it by setting up our visitor's/caretaker's cottage with its *own* solar system that automatically shut down if sustained current draw exceeded a pre-settable level, or battery charge fell below 55% remaining. Doing so resulted in complaints - but vaguely worked.

We now live in Sydney, but retain our previous mode of electricity usage - resulting in our house running more than comfortably on a 2.4 kW grid connect system and solar water heating. Now, when visitors stay, it's the power grid that gets thumped.

Walking the walk

My interest in much of this goes back to the mid-1950s whilst working in the research division of General Motors. I had been attempting to simulate rough road conditions - but not enough was known about road conditions encountered in Africa (the main export market). With the backing of Mobil Oil, I elected to find out myself.

The author and the QLR in El Golea oasis (Sahara) in 1959. Pic: Tony Fleming.

I used a rare QLR Bedford 4X4 truck that had been built in WW2 as a mobile airfield control centre, but had never been previously used. It had a huge (350 amp) dynamo - ideal to drive the electrics required.

Fuel storage was increased to 1270 litres - a necessary range of 5000-6000 km.

A colleague (Tony Fleming) and I drove it twice the length and breadth of Africa (including Saharan crossings).

The trip later became semi-famous. Africa was falling apart politically at the time. The Sahara route was closed the very day we completed the return crossing (in 1961) and has never reopened. The QLR was the very last vehicle across that central Africa route. A *superb* DVD of our trip is now available (page 94.)

The adventure initiated a life-long interest in outback travel.

VW Kombi

In 1994 my wife and I rebuilt a 1974 Kombi adding a 100 Ah auxiliary battery charged by the alternator plus a 100 watt solar module. This ran a 32 litre Engel fridge and minor lighting.

It worked reliably but lack of monitoring back then made it hard to gain data or track down failings.

Our Kombi in camp at nightfall, about 200 km north of Birdsville, Qld, in 1996. Pic: Author - copyright caravanandmotorhomebooks.com.

OKA crossing the Wenlock River (Cape York). The roof dome houses the antenna of the Westinghouse satellite phone.

OKA

We also rebuilt a 1994 OKA (ex mining vehicle) and drove it many times across Australia, over mostly inland tracks.

A 140 amp alternator charged three 100 Ah deep cycle batteries, aided by two 80 watt solar modules. This drove a 71 litre Autofridge, a laptop computer and printer, ten halogen lights, and a huge Westinghouse satellite 'phone.

Later, an Iridium sat-phone enabled running on one battery and solar alone.

Nissan Patrol & Tvan

Our subsequent 2005 4.2 litre TD Nissan Patrol had a permanently 'on' 60 litre fridge, driven by two 80 watt roof-mounted modules via a PL40 (and later, and on long-term trial, the very first Redarc BMS 1215) and an 105 amp-hour AGM battery.

The fully off-road Tvan camping trailer had one 50 watt roof-mounted module that charged a 100 Ah trailer-located AGM battery via its own solar regulator (it had no alternator feed).

Nissan Patrol and Tvan each had its own solar modules, regulator and battery. Its provision for alternator charging was never needed. Pic: Author - Mitchell Falls 2009.

This basic system adequately powered three LED lights, a water pump and a NextG Blue modem and a laptop computer. It proved to be totally reliable. This concept of twin but separate solar systems works superbly.

Home & property

In 1999 we bought 10 acres of virgin bush adjoining the Indian ocean north of Broome. Our house (and property) ran from solar alone. The self-built house was even *constructed* using almost only solar power.

Our own designed and built solar system generated up to 17 kWh a day.

The solar array had thirty 120 watt and 130 watt modules running at a nominal 72 volts into an Outback Power MPPT 60 amp regulator. They charged 16 gel cells, (960 Ah) at 48 volts (14-17 kWh/day.)

An SEA 48 volt inverter ran a 500 litre fridge, dishwasher, washing machine, two computers, 104 cm TV, kitchen appliances, and thirty compact fluorescent globes.

Swimming pool

Re-circulating the water in the 31,000 litre swimming pool would normally require 3-5 kW/day and a $50,000 plus system if using normal (230 volt ac) technology.

We installed a 48 volt dc brushless Lorenz motor pump driven (no batteries) from four 120 watt modules via a Lorenz 48 volt MPPT regulator.

It re-circulated 3000-5000 litres an hour between sun-up and sun-down.

Including the cyclone-resistant solar mounting, it cost just under $7500.

The pump's solar array just visible bottom right. Behind is a tidal lagoon - with the Indian ocean in the distance. Pic: Author 2007.
Copyright: successfulsolarbooks.com.

Water pumping

All washing and toilet flushing water was pumped from a 100,000 litre rain-water tank that comfortably filled about half-way through the yearly wet season.

Water was pumped to the house by a 230 volt, 750 watt Grundfoss centrifugal pump that initially ran each time water was drawn. It used about 1 kWh/day, but adding a 450 litre pressure tank reduced that by an extraordinary 95%. It subsequently ran only once or twice a day - for about three minutes each time. Water was thus delivered almost entirely smoothly and silently by the tank's air pressure alone. We sold this property in mid 2010 and moved back to Sydney to be close to our family.

Church Point

Home is now an environmentally designed house in Church Point (NSW) overlooking Pittwater. It is north-facing and partially recessed into a steep hillside. Most of the rear is underground. All walls are Hebel (aerated concrete block) or reinforced concrete. The resultant thermal mass keeps the house between 17^0-19^0 C degrees throughout winter. It needs only minor heating.

We installed a 2.4 kW grid-connect solar system that originally fed 40% of its output into the grid during winter. Realising that, we installed three Daiken reverse cycle air conditioners that, in winter, run on their ultra-efficient heating cycle all the day to heat up the thermal mass. Each provides over 3.5 kW of heat for under 700 watts drawn but are rarely needed at that level. Summer temperature remains at a constant 23^0-24^0 C excepting for the ground floor vestibule which stays at around 21^0 C.

We evaluated going off-grid - converting the system to stand-alone operation with battery back-up but found it (currently) preferable to retain the grid supply to charge a battery bank during a low-cost 10 pm to 7 am tariff for use at night and to cope with rare peak loads.

The 2.4 kW array is mounted at a lower angle than usual, such that it melds into the curved roof. It also benefits from irradiation being reflected upward from Pittwater (immediately in front of the house) and reflected back down again by light haze and scattered cloud. Input is 10%-15% higher than normal on some days. Pic: successfulsolarbooks.com

Africa - DVD

My companion on the Africa trip (Tony Fleming) is a superb documentary maker. To celebrate the trip's 50th anniversary he had all the colour slides surgically cleaned and scanned at 3400 dpi. Tony then made this superb voice-over 43 minute DVD.

It is available Caravan & Motorhome Books, PO Box 356, Church Point, NSW 2105 (or via telephone 02 9997 1052 (during business hours). Price is A$16 post free - or five for $60 post free.

The trip is also described in detail at: http://caravanandmotorhomebooks.com/last-drive-across-africa/

Electricity - simply explained

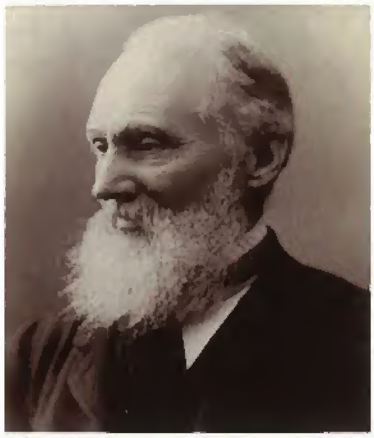
What is electricity?

In the mid-1850s, the great scientific pioneer, Lord Kelvin was lecturing on electricity. He asked his class: "*What is electricity*".

One student put his hand up, but then stammered out that he'd forgotten. Lord Kelvin turned slowly to the class, and said:

"*Gentlemen, you have just witnessed the greatest tragedy of this century. Only two people know what electricity is. One is God, and the other one is Mr Smith. God won't tell us - and Mr Smith has forgotten*".

To this day no-one truly knows, but whilst its exact nature is yet to be fully defined, its behaviour has been surprising well understood since the days of Lord Kelvin and many other scientists of his era.



Lord Kelvin - source unknown.

General

Alternating and Direct Current: the movement of electrons responsible for the flow of electricity. Direct current flows and performs work in a manner analogous to a band saw: it operates in a continuous direction. Alternating current works much as big cross-cut saws that operate by being pulled to and fro. Preferred abbreviations are now ac and dc respectively (previously AC/DC).

Electricity authorities supply alternating current (although Broome and a few other Australian country towns ran on dc until the 1960s). Batteries supply direct current. It is readily possible to convert alternating current into direct current - and vice versa. (An inverter converts direct current into a higher voltage alternating current, a mains battery charger converts alternating current into a lower voltage direct current.)

Solar panels/modules: The solar industry describes individual solar generating units as solar modules, 'solar panels' are assemblies of modules. Assemblies of modules are called 'arrays'.

Standards: In all Australian/New Zealand Standards 'should' is a suggestion or recommendation only. 'Shall' is a requirement that *must* be followed to comply with that Standard.

Electrical units & terms

Amps: the amount of electrical current that is flowing. It is akin to *flow* in a pipe. The greater the voltage, the greater the amount of current that will consequently flow. Its common abbreviation is A, (but that of current generally, when used in a formal equation, is I).

Amp-hour: the amount of electrical current that flows in one hour. A device that generates four amps for five hours thus produces 20 amp-hours: amp-hour is commonly abbreviated to Ah.

Extra-low voltage: voltage not exceeding 50 Vac, or ripple-free voltage not exceeding 120 Vdc.

Low voltage: voltage exceeding extra-low voltage, but not exceeding 1000 volt ac, or 1500 volt dc.

High voltage: any voltage (ac or dc) that exceeds low voltage.

Ohms: The unit of resistance to the flow of an electric current. The unit is either spelled out (i.e. as ohm), sometimes expressed as R, and (traditionally) also expressed by using the Greek symbol for omega (Ω). One ohm is the equal to the resistance to the flow of current through which a current of one amp will flow if one volt is applied across it.

Ohm's Law: a fundamental electrical law. Volts, amps and ohms are interrelated and that interrelationship is expressed and defined by Ohm's Law. That law states that the direct current (dc) that

flows in a circuit is directly proportional to the voltage across that circuit. It is valid for metal circuits and some (but not all) liquids that are electrically conductive.

Power/Energy: These terms are often misused. Power relates to the *rate* at which work is done and is expressed in watts. Energy relates to the *amount* of work done and is expressed in watt-hours.

Resistance: To varying extents, all substances resist the flow of electricity. This resistance generates heat. Resistance can be useful (it is how an electric kettle works) but where heat is not specifically required, it wastes energy. The thicker a cable, the lower its resistance - and the less the energy lost through heat. The term 'resistance' is itself often abbreviated as R. It is measured in ohms (page 95).

Volts: the pressure that causes electricity to flow: akin to *pressure* in a pipe (abbreviated V). It is common to indicate whether such voltage is ac or dc - e.g, Vac or Vdc. (In formal equations it is E.)

Watts: Volts, amps and ohms are interrelated and, when multiplied together are a measure of energy used, and also of work performed. The resultant unit is a watt (abbreviated as W). Thus one volt times one amp equals one watt. See also Energy/Power on the previous page.

Watt-hour: a measure of electricity generated or used in one hour. A 100 watt globe that is running for 30 minutes consumes 50 watt-hours. A 12 volt solar module producing four amps for five hours produces 4 (amps) x 12 (volts) x 5 (hours) = 240 watt-hours. The correct abbreviation is Wh.

Watt-hours/day: the number of watt-hours consumed in a 24 hour period. This unit is handy when scaling solar systems etc. The correct abbreviation is Wh/day.

Making contact

Early editions of this books, included supplier contact details that often became out-of-date. The ease of locating via Google and the Internet largely removed this need. Now, many companies wish *only* to use email - and deliberately omit their postal address in their promotions. There is also a proliferation of local and overseas on-line vendors, and many solicit only Internet sales.

'Googling' what you seek will return many links, some of which may not be current or exactly what you are looking for, but will certainly be superior to a static list. For these and other reasons this book no longer lists contact details in printed form.

Companies can often be located via their trade name followed by .com.au (for some Australian companies). Others, including ourselves, have only .com. There are also geographical and organisational suffixes: e.g., New Zealand uses .nz. Organisations are likely to use .org. (Only Internet Explorer now requires you to enter www: as a prefix).

Where the company name is more than one word (e.g., our own *Caravan & Motorhome Books*), try joining the words together, omitting upper case letters, and spelling out '&' as 'and'. Thus of our two websites, one is caravanandmotorhomebooks.com - the other is successfulsolarbooks.com.

Where the above does not work try using a hyphen: e.g: eastpenn-deka.com. Another way is to search using the on-line Yellow Pages.

Useful sites

An excellent example of a really well-run source of specialised information is the camper trailer site campertrailers.org. For 4WD owners, caravans and related topics, I recommend exploroz.com.

Our main website (caravanandmotorhomebooks.com) contains over 80 articles over a wide range of topics. All were totally revised and updated in late 2015 and are now typically updated monthly. It also has Links to other sites of interest. Our associated successfulsolarbooks.com is likewise being updated.

Some useful information can be found on web forums, but much is worthless and sometimes downright dangerous. It is mostly of value if you know already know about the topic.

This virtually all-new third edition explains, in clear English, every detail of designing and installing solar in cabins, camper trailers, caravans and motor homes. It complements the companion book Solar Success - that does the same for homes and properties of all sizes (including grid-connect).

Author/engineer, Collyn Rivers practices what he says. He has designed and built solar systems of all sizes, from a big property system in the Kimberley, and RV systems from Kombi to off-road truck size. He and his wife currently live in an all-solar home in Church Point, NSW, Australia.

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